The Jurassic Curtis, Summerville and Stump formations of Utah and Colorado consist of marine and marginal-marine strata deposited along the southern margin of the Western Interior Seaway. These rocks consist of conglomerates, sandstones, mudstones, and limestones, which crop out along the flanks of the Uinta Mountains in northeast Utah and northwest Colorado, and in the San Rafael Swell in central Utah. Although previous investigations have documented the distribution, lithologic characteristics, and interpreted depositional environments of these units, they have been difficult to correlate regionally due to internal lithofacies variations and the lack of age-diagnostic fossils. Within this study I present new data consisting of 34 biostratigraphic samples and 25 measured stratigraphic sections demonstrating the stratigraphic equivalency of the Curtis and Summerville formations with the Stump Formation. Within the basal Curtis and Stump formations, palynological samples containing the index dinoflagellate cyst species *Wanea fimbriata* and *Stephanelytron redcliffense* indicate an early Oxfordian age of deposition. This early Oxfordian age designation is further supported by ammonite specimens (*Quenstedtoceras (Pavloviceras) sp*) collected from the basal portion of these formations. This new biostratigraphic data, when combined with the age of the overlying Morrison Formation, brackets the age of Curtis/Summerville and Stump deposition from early to late Oxfordian time (~161-155 Ma).

Detailed sedimentological field data allows formulation of a sequence-stratigraphic model that indicates these formations were deposited during a single transgressive-regressive sequence. Outcrop gamma logs and petroleum industry borehole gamma-ray logs were utilized to trace the interpreted sequence stratigraphic surfaces beneath the Uinta basin. The new sequence stratigraphic model for Curtis, Summerville and Stump formation deposition helps clarify the stratigraphic architecture of the Middle-Upper Jurassic rock of Utah and northwest Colorado, and allows for detailed paleoenvironmental reconstructions of the final stage of the Jurassic Western Interior seaway deposition. Additionally, the new model may serve as a guide for future sequence-stratigraphic interpretations of other tidally-influenced depositional systems.
SEQUENCE STRATIGRAPHY OF THE CURTIS, SUMMERVILLE AND STUMP FORMATIONS, UTAH AND NORTHWEST COLORADO

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INTRODUCTION

The Curtis, Summerville and Stump formations of Utah and northwestern Colorado consist of marine and marginal-marine strata deposited along the southern margin of the Jurassic Western Interior Seaway. These rocks, which consist of conglomerates, sandstones, mudstones, and limestones, crop out along the flanks of the Uinta Mountains in northeastern Utah and northwestern Colorado, and the San Rafael Swell in central Utah (Figure 1). Although previous investigations of the Curtis, Summerville and Stump formations have documented their distribution, lithological characteristics, and interpreted depositional environments (Gilluly and Reeside, 1928; Thomas and Krueger, 1946; Caputo, 1988), these units have been difficult to correlate regionally because of internal lithofacies variations and a paucity of age-diagnostic fossils. This has resulted in disparate paleoenvironmental reconstructions for the Uinta Mountain and San Rafael regions, which in turn has hampered interpretations of the Middle-Late Jurassic depositional history of the basin.

This study focuses on redefining the regional stratigraphic relationships of the Curtis, Summerville, and Stump formations in Utah and Colorado using new biostratigraphic and sedimentologic data collected from 25 measured stratigraphic sections (Figure 1). This new data, when combined with data from previous investigations, allows a detailed regional correlation of the Curtis, Summerville and Stump formations. Additionally, these data also allow the application of a new sequence stratigraphic model that helps explain the final phase of deposition in the southern part of the Jurassic Interior Seaway.

METHODS

The Curtis, Summerville, and Stump formations in the study area were investigated by measuring a total of 25 vertical measured sections (totaling ~2.5 km) along well exposed outcrops in the Uinta and San Rafael Swell regions (Figure 1). Sedimentological observations include descriptions of lithologies, sedimentary and biogenic structures, paleocurrent measurements, and fossils with at ~10 cm resolution. Attention was also paid to the recognition and interpretation of regionally extensive bounding surfaces formed in response to basin accommodation changes. These surfaces
were interpreted using sequence-stratigraphic terminology following the concepts presented by Van Wagoner et al. (1988) and Catuneanu (2006).

Thirteen gamma ray logs were also generated at selected section locations in order to correlate the described lithologies and sequence stratigraphic surfaces into the subsurface. Gamma ray logs were generated using a handheld scintillometer with the average of 10 gamma ray readings taken at 30 cm intervals up section. Sample locations were trenched to bedrock in order to insure an accurate gamma ray signature. Outcrop sedimentological and gamma logs were correlated with petroleum industry geophysical well log data from the Uinta basin obtained from Utah Geological Survey and MJ Systems archives. Landmark Geographix software was used in the regional correlations.

Age control for these units was obtained by collecting a total of 29 palynology samples and 5 ammonite fossils collected across the study area. Palynology samples were collected in grey to black organic rich marine mudstones and shales and selectively sampled above and below significant sequence stratigraphic boundaries in order to investigate as to their temporal significance extent. Three section locations were sampled at regular intervals up the complete section in order to constrain up section age control. Samples were processed and interpreted by professional palynologist Gerald Waanders.

GEOLoGIC sETTING

The study area in eastern Utah and western Colorado is situated in the northern part of the Colorado Plateau. During deposition of the Curtis, Summerville, and Stump formations this region was situated at the southwest margin of the Western Interior Seaway in the foreland of the developing North American Cordillera. The Mesozoic Cordillera was a complex orogen formed in response to the subduction/collision of oceanic plates and exotic terranes with western margin of North American (Armstrong and Oriel, 1965; Hamilton, 1978; Dickinson and Snyder, 1978; Lawton, 1994). During the Jurassic, the sedimentary basin in which the Curtis, Summerville and Stump formations were deposited was bordered on the west by the
Figure 1. Location maps of the study area. (A) Shaded area represents the location of the study area in Utah and northwestern Colorado. (B) Distribution of Upper Jurassic rock outcrops across the region (shaded blue). Numbers 1-25 correspond to measured section locations. San Rafael Swell Region: 1, Last Chance Wash; 2, West I-70; 3, Moore Cutoff; 4, Dutchmans Flats; 5, San Rafael River; 6, Cedar Mountain 1; 7, Cedar Mountain 2; 8, Cedar Mountain 3; 9, Humbug Canyon; 10, Price River; 11, Neversweat Wash; 12, Dry Mesa; 13, Tidwell; 14, East I-70. Uinta Mountain Region: 15, Finch Draw; 16, Irish Canyon; 17, Deerlodge Park; 18, Steineker; 19, Red Fleet; 20, Island Park 2; 21, Island Park 1; 22, Orchid Draw; 23, Chew Ranch; 24, Trail Creek; 25, Hanna. Geographical coordinates and detailed logs of each measured section are listed in Appendix A.
Cordillera, to the east by the North American craton, and to the south by the Mogollon Highlands, an uplifted rift shoulder associated with back-arc rifting of the McCoy-Bisbee-Chihuahua trough (Bilodeau, 1986; Lawton, 1994). Regional deposition in the Jurassic Cordilleran foreland was influenced by the development of dynamic topography associated with oceanic plate subduction subduction along the western margin of North America (Lawton, 1994; Currie, 1998a).

From Late Cretaceous to Eocene time, the Cordilleran foreland basin underwent tectonic partitioning and deformation by basement-cored uplifts during the Laramide orogeny (Dickenson and Snyder, 1978). The study area contains well-exposed outcrops of the Curtis, Summerville, and Stump Formations along the flanks of the Laramide Uinta Mountains in Utah and Colorado, and in the San Rafael Swell in east-central Utah.

**STRATIGRAPHY**

The Jurassic rocks of the Western Interior basin consist of marine, tidal, and nonmarine deposits that contain six regional sequence-bounding unconformities (Pipiringos and O’Sullivan, 1978). Although defined by sparse biostratigraphic evidence, these unconformities (termed J0 through J5) have been traced regionally using lithostratigraphic principles (Imlay, 1980). In the study area, Curtis, Summerville and Stump formations are interpreted as being bounded at the base by the J3 unconformity and at the top by the J5 unconformity (Pipiringos and O’Sullivan, 1978). The existing regional stratigraphic relationships are shown in Figure 2 and discussed in more detail below.

**Uinta Mountains**

In the Uinta Mountain region, the Jurassic rocks between the J3 and J5 unconformities consist of the Curtis and Redwater members of the Stump Formation (Pipiringos and Imlay, 1978). The Curtis Member is ~10-50 m thick and consists primarily of tan/gray, coarse- to very fine-grained sandstone with thin interbeds of green-gray siltstone and mudstone. The Redwater Member is composed of ~20-35 m of gray mudstone with thin interbeds of medium- to very fine-grained sandstone.
Figure 2. Time-stratigraphic chart of Middle-Upper Jurassic rocks of Utah and northwestern Colorado (modified from Imlay, 1980). These correlations were primarily based on lithological similarities between units, the stratigraphic position of interpreted regional unconformities, and limited biostratigraphic data. In the western part of the Uinta region, however, the J3 unconformity is absent as the Curtis Member is conformable with the underlying tidal deposits of the Preuss Formation.
and sandy fossiliferous-oolitic grainstone. In the eastern part of the study area the Curtis Member is separated from the underlying eolian strata of the Middle Jurassic Entrada Formation by the J3 unconformity (Pipiringos and Imlay, 1978; Eschner and Kocurek, 1986). In the western part of the Uinta region, however, the J3 unconformity is absent as the Curtis Member is conformable with the underlying tidal deposits of the Preuss Formation (Thomas and Krueger, 1946; Pipiringos and Imlay, 1979; Peterson, 1994).

Across the entire study area, the top of the Curtis Member is marked by a disconformity (J4 unconformity) above which rests the lower-middle Oxfordian Redwater Member (Imlay, 1980). The Redwater Member is overlain by shallow-marine, tidal, and eolian strata of the Morrison Formation (Currie, 1998b). The contact between the Redwater Member and the Morrison Formation was originally thought to represent the J5 unconformity based on correlations with Upper Jurassic rocks in Wyoming (Imlay, 1980). However, more-recently the contact between the Redwater Member and Morrison Formation has been interpreted as conformable, based on the up-section transition from shallow-marine to tidal lithofacies observed in the two units (Currie, 1998b).

San Rafael Swell

In the San Rafael Swell region of east-central Utah, the Jurassic rocks between the J3 and J5 unconformities consist of the Curtis and Summerville formations (Gilluly and Reeside, 1928). The Curtis Formation is ~50-70 m thick and is made up by glauconitic, green/gray, coarse- to very fine-grained sandstone with lesser amounts of conglomerate and mudstone. The Curtis Formation is separated from the underlying eolian strata of the middle Jurassic Entrada Formation by the J3 unconformity (Pipiringos and O’Sullivan, 1978). This surface within the study area is sharp, and locally erosional (with relief up to 10m), and is commonly marked by a basal conglomeratic unit (Caputo, 1988). The uppermost 5-8 m of the Curtis Formation consists of a grey mudstone and intercalated sandstone, which conformably grades upward into the red mudstones of the Summerville Formation.

The overlying Summerville Formation is ~35-100 m thick and consists primarily of red mudstone and thin interbeds of green and red sandstone with considerable amounts of gypsum near the top of the unit. In the Rafael Swell region, the top of the Summerville Formation is overlain by late Oxfordian fluvial/lacustrine deposits of the
Morrison Formation (Tidwell Member) (Demko et al., 2005). The contact between the two formations is marked by the J5 unconformity. Along the eastern and northern part of the San Rafael Swell, there is angular truncation of beds in the Summerville Formation along the unconformity surface (Figure 3) (Trimble and Doelling, 1978).

**STRATIGRAPHIC AGE**

Previous age determinations for the Stump Formation in the Uinta Mountain region are based on regional correlations of the Curtis Member and ammonites identified within the Redwater Member (Imlay, 1980; Imlay, 1982). The Curtis Member has been classified previously as late-middle Callovian in age based on lithological similarities with the Pine Butte Member of the Sundance Formation in Wyoming (Figure 2; Imlay, 1980). The Redwater Member is considered early to middle Oxfordian based on the ammonites *Cardioceras* and *Goliathoceras* identified within the unit in Wyoming (Imlay, 1982). Although the upper-most Redwater Member has not been previously dated, the unit is overlain by the Oxfordian-aged Morrison Formation (Currie, 1998b). An Oxfordian age for the basal Morrison Formation is based on $^{40}$Ar/$^{39}$Ar dating of sanidine crystals derived from a bentonite collected 2.4 m above the base of the unit near the Island Park 1 section (Kowallis et al., 1998). The 154.8 ± 0.6 Ma age of this altered ash bed corresponds to the latest Oxfordian based on the timescale of Gradstein et al. (2005).

Past age determinations for the Curtis and Summerville formations in the San Rafael Swell region are based primarily on regional lithostratigraphic correlations (Figure 2). A previous investigation assigned the Curtis Formation a late-middle Callovian age based on its similarity to the Pine Butte Member of the Sundance Formation in Wyoming and the Curtis Member of the Stump Formation in northeastern Utah (Imlay, 1980). Since the Curtis grades conformably into the overlying Summerville, it has been reasoned that the Summerville is only slightly younger in age than the Curtis Formation (Imlay, 1980). Consequently, the entire Curtis/Summerville interval has been as interpreted as late-middle Callovian in age. Because of this correlation, the J4 unconformity identified in the Uinta mountain region is interpreted to merge with the J5 unconformity on the San Rafael Swell (Pipiringos and O'Sullivan, 1978). A late Oxfordian age of the lower
Figure 3. Angular discordance along the contact of the Summerville Formation and overlying Morrison Formation, I-70 East section (Section 14, Figure 1), San Rafael Swell.
Morrison Formation in the San Rafael Swell region is suggested by the presence of Oxfordian charophytes collected from the lower parts of the formation east of the study area near Grand Junction, CO (Shudeck et al., 1998) and 40Ar/39Ar dating of sanidine crystals derived from a bentonite collected ~3 m from the base of the formation just to the south of the San Rafael Swell (Kowallis et al., 1998). The 154.82 ±0.58 Ma age of this altered ash bed corresponds to the latest Oxfordian based on the timescale of Gradstein et al. (2004). As this age is nearly identical to the age of the lower Morrison ash dated from the Uinta Mountain region, it suggests that the lower Morrison Formation is late Oxfordian in age across the entire study area (Kowallis et al., 1998).

**New Palynology and Ammonite Biostratigraphic Data**

In order to help refine the stratigraphic age of the Curtis, Summerville and Stump formations, a total of 29 palynology samples and 5 ammonite fossils were collected across the study area. At the Dry Mesa section on the San Rafael Swell (Section 12, Figure 4), palynology samples were collected at regular intervals throughout the Curtis Formation. Samples collected between 3.5 m and 15 m above the base of the unit yielded a large diversity of well-preserved microplankton, spores and pollen. The lower-most sample collected 3.5m from the base of the section included the dinoflagellate cyst species *Wanea fimbriata* and *Stephanelytron redcliffense*, both of which indicate an Early Oxfordian age (Figure 5; Gradstein et al., 2005). Samples up to 15 m above the base of the formation also include *Stephanelytron redcliffense* also indicative of an Early Oxfordian age. Samples collected from the upper Curtis Formation, however, were indeterminate.

This early Oxfordian age designation for the lower Curtis Formation is further supported by an ammonite specimen that was collected ~9 m above the base of the section at Dry Mesa. The ammonite, identified as *Quenstedoceras (Pavloviceras)* sp. (Figure 5) is restricted to the latest Callovian to early Oxfordian (Imlay, 1982).

In the Uinta mountain region, the Curtis and Redwater members of the Stump Formation were sampled for palynological content (Figure 4). At Red Fleet, a sample
Figure 4. Stratigraphic position of palynology/ammonite samples in the Uinta Mountains and San Rafael Swell regions. Sample locations are referred to in the text and listed in Appendix A.
collected at 3.5 m above the base of the Curtis Member, yielded the early Oxfordian
dinoflagellate cyst *Stephanelytron redcliffense*. In addition, 14 m above the base of the
section, ammonites collected from the basal Redwater Member included *Quenstedoceras*
(*Pavloviceras*) sp. and *Cardioceras Scarburghiceras Wyomingense*, further supporting an
interpreted early Oxfordian age of deposition (Figure 5) (Imlay, 1982).

Palynology samples collected from the middle to upper part of the Redwater
Shale Member (between 33-44 m in the section; Figure 4) yielded several dinoflagellate
species including *Rynchodiniopsis cladophora*, *Sentusidinium villersense*,
*Sirmiodiniopsis orbis*, *Acanthaulax senta*, *Ellipsoidictyum cinctum*, *E. retiuculatum*, and
*Gonyaulacysta jurassica*. This assemblage indicates an early-middle Oxfordian age of
deposition of the sampled interval (G. Waanders, personal communication, 2005).

At Deer Loge Park, nine samples from the Redwater Member yielded a diverse
and well-preserved assemblage of both terrestrial and marine palynomorphs (Figure 4).
An early Oxfordian age for the sampled interval between 2.3-36.5 m is indicated by
occurrences of the dinoflagellate cysts *Wanea fimbriata*, *Stephanelytron redcliffense*, and
*Nannoceratopsis pellucida*.

The new biostratigraphic data presented above redefines the age of the Curtis
Member of the Stump Formation in the Uinta Mountain region, and the Curtis and
Summerville formations in east-central Utah from their current late-middle Callovian
designation to Oxfordian in age (Figure 6). The data also indicate that both the J4 and J5
unconformities represent intra-Oxfordian depositional hiatuses within the basin.
Moreover, the palynological and ammonite fossils identify the temporal equivalence of
the Curtis Formation in east-central Utah and the Stump Formation in the Uinta Mountain
region.

A complete list of identified palynomorphs, stratigraphic distribution of taxa,
photos of the common and age diagnostic palynomorph species, thermal alteration index
and the kerogen content of recovered organic material, are included in Appendix B and
Appendix C.

**SEDIMENTOLOGY**

In order to provide the basis for interpreting the sequence stratigraphic context of
the Curtis, Summerville and Stump formations in the study area, the lithological and
Figure 5. Stratigraphic range of collected ammonites and age-diagnostic dinoflagellate cysts species. Age overlap suggests an Early Oxfordian age of deposition for both the lowermost Curtis Formation on the San Rafael Swell and the Curtis Member of the Stump Formation in the Uinta Mountain region. Stratigraphic age designations based on Gradstein et al. (2005).
Figure 6. Time-stratigraphic chart displaying the new stratigraphic age determinations and regional correlations of the Curtis, Summerville and Stump formations in the study area.
sedimentological characteristics of 25 outcrop stratigraphic sections of these units were documented in the Uinta Mountain and San Rafael Swell regions. Internally, these formations consist of up to 180 m of sandstone, mudstone, conglomerate, and minor limestone that within this study are subdivided into 12 lithofacies assemblages. These assemblages are interpreted to have been produced by a particular hydrodynamic process or suite of processes occurring within basin, and thus are used to interpret overall depositional environment. Each assemblage is classified based on the characteristics of the dominant facies in the assemblage. Individual stratigraphic units and their dominant lithofacies assemblages are described in detail below.

Curtis Formation

The Curtis Formation in east-central Utah can be subdivided into 5 generalized lithofacies assemblages (Figure 7). The primary assemblages include an incised channel-form sandstone (C1), fossiliferous gravelly sandstone (C2), heterolithic sandstone/mudstone/conglomerate (C3), interbedded trough cross-stratified and horizontally stratified sandstone (C4), and upward fining heterolithic sandstone/mudstone (C5).

Incised channel-form sandstone (C1)

Facies assemblage C1 consists of lenticular beds of medium/coarse-grained sandstone with granule-pebble-sized gravel and mud rip-up clasts. Facies C1 fills erosional scours up to 10 m deep and 200 m wide cut into the underlying Entrada Formation (Figure 8). Sandstone beds also contain brachiopod and echinoid shell fragments as well as glauconite grains. Individual sandstone lenses are up to 10 m thick and up to 200 m in width when measured perpendicular to paleoflow direction. Sedimentary structures include trough and planar cross-stratification, ripple cross-lamination, as well as massive bedding. Individual beds range from 1-4 m thick. Paleocurrent data collected from foreset-dip orientations show a dominance of paleoflow to the northeast (Caputo, 1988; Dickey and Wright, 1958).

Facies assemblage C1 is interpreted as the deposits of tidal-channels that filled erosional gullies cut into the underlying Entrada Formation. This interpretation is based on sedimentary structures that indicate deposition by unidirectional currents, along with
Figure 7. Generalized stratigraphic log of the Curtis Formation from the San Rafael Swell showing lithologies, dominant sedimentary structures, and interpreted lithofacies assemblages (C1-C5).
Figure 8. Photograph of incised channel-form sandstone (C1) of the Curtis Formation near Humbug Canyon (Section 9), San Rafael Swell. C1 facies fill erosional scours cut into the underlying Entrada Formation during development of the J3 unconformity.
the presence of marine-fossils and glauconite grains. The laterally discontinuous nature of these channels, as well as the abundance of extra-basin conglomerate clasts (i.e. Paleozoic chert and sandstone; Caputo, 1988; Peterson, 1988), suggests the channels may have been associated with fluvial systems incised into the Entrada Formation during development of the J3 unconformity. Given that facies C1 paleoflow indicators are directed towards marine-dominated areas of the basin northeast of the study area, it appears that facies C1 tidal channels were ebb dominated.

**Fossiliferous gravelly sandstone (C2)**

Facies assemblage C2 consists of tabular beds of fossiliferous glauconitic sandstone and conglomerate that reaches a maximum of 50 cm thick (Figure 9B). Conglomerate clasts range from granule- to cobble-size. Observed fossils consist of brachiopod, mollusk, and echinoderms fragments. These beds also contain abundant vertical and horizontal burrows. Facies C2 beds cap the incised channel-fill deposits of facies C1 or rest directly above the Entrada Formation where facies assemblage C1 is absent. In some cases vertical burrows extend downward through facies assemblage C2 beds into the underlying Entrada Formation.

Facies assemblage C2 is interpreted as transgressive lag deposits formed when the study areas was initially inundated by the Western Interior seaway during the Late Jurassic. Gravels in this facies probably originated as post-storm lags accumulated on a regional wave ravinement surface, or were reworked from clasts that accumulated on the J-3 unconformity surface. The observed fossil and trace fossils observed are consistent with lag deposits from storm- tide-influenced shelf deposits (Prave et. al. 1996).

**Heterolithic sandstone/mudstone/conglomerate (C3):**

Facies assemblage C3 is 10-35 m thick and contains three subfacies including: a) mudstone-siltstone, b) channel-form sandstone and conglomerate, and c) lenticular-, wavy-, and flaser-bedded sandstone and shale (Figure 9). Overall, facies assemblage C3 forms an upward coarsening package that is erosionally truncated at the top by beds of facies assemblage C4 (Figure 9).

Subfacies C3a is characterized by up to 6 m of calcareous laminated black to gray mudstones. The subfacies also contains thin to very thin interbeds (1-5 cm thick) of
Figure 9. A) Outcrop photograph of basal Curtis Formation near I-70 West (Section 2), showing up-section transition of facies C2, C3, and C4. At this location Facies C3 is gradational from offshore shelf (C3a) to tidal shoreface (C3c) deposits before being erosionally overlain by C4a tidal channel deposits. B) Facies C2 and C3a above the contact with the underlying Entrada Formation (San Rafael River, Section 5). C) Close up of facies C3b lenticular tidal channel deposits resting directly on the Entrada Formation (Cedar Mountain 3, Section 8). D) Close up of facies C3c heterolithic tidal shoreface deposits (San Rafael River, Section 5).
siltstone and very fine-grained sandstone containing unidirectional ripple cross lamination and small-scale hummocky cross stratification. This unit is organic rich and contains a large diversity of marine palynomorphs. Facies C3a also contains abundant horizontal trace fossils (*planolites, chondrites*), and rare echinoderm and ammonite fossils. Ammonites are associated with calcareous concretions that are up to 20 cm in diameter.

Facies C3b consists of lenticular beds of coarse-grained sandstone and conglomerate, 1-8 m thick and hundreds of meters wide (Figure 9C). These conglomeritic sandstones have erosional bases and are incised into subfacies C3a at the base or interbedded with subfacies C3c (Figure 10). Sedimentary structures include trough and planar cross-stratification. In some instances, siltstone laminations drape trough foresets. Paleocurrent data collected from foreset-dip orientations show a dominance of paleoflow to the northeast. These sandstone and conglomerates also contain abundant plant fragments and brachiopod, echinoid, and ammonite fossils. Up section, subfacies C3a is overlain erosionally by subfacies C3b or is gradational with subfacies C3c.

Subfacies C3c consists of up to 30 m of upward-coarsening, rhythmically bundled, parallel to ripple-cross laminated, green-gray mudstone and sandstone. Intercalated sandstones and mudstones display a transition from lenticular to wavy to flaser bedding up section (Figure 9). Sandstones within this facies are fine-medium grained, ripple-cross laminated and are locally glauconitic. Other sedimentary structures include mud-draped wave and unidirectional current ripples. In some instances asymmetric ripple laminae have opposite dip directions in adjacent sets. Mudstones from this unit contain abundant marine and terrestrial palynomorphs and contain numerous horizontal feeding traces and arthropod resting traces.

Individual beds in subfacies C3c are tabular, but in some areas form large-scale clinoforms that dip at angles up to 10° (Figure 10). These clinoform beds are interbedded with subfacies C3b, and downlap onto the regional flooding surface/J3 unconformity (see above).

Facies C3 is interpreted to represent deposits of off-shore marine, tidal channel, and tidally-influenced shoreface environments. Within this facies assemblage, subfacies a, b, and c represent lateral variability of environments across the region during the time
Figure 10. Outcrop photograph of the Curtis Formation at Cedar Mountain 3 stratigraphic section showing large-scale clinoform beds downlapping onto superposed J3 unconformity/maximum flooding surface (blue line). Insets show closer view of intercalation of facies C3b and C3c at the toes of clinoform beds. See Figure 1 for location.
of deposition. Facies C3a is interpreted as marine shelf deposits, below fair-weather wave base. The fine laminations and the abundance of horizontal trace fossils suggests a low energy and low stress environment where the dominant mode of sedimentation was suspension settling. The presence of echinoderm fossils suggests an environment with normal-marine salinities. The ripple-cross laminated and hummocky cross-stratified siltstone and sandstone within this unit indicate deposition was periodically influenced by unidirectional currents and waves, most-likely generated by storms.

The lenticular, cross-stratified conglomeritic sandstones within facies C3b are interpreted to as tidal channel deposits that formed offshore of an open-coast sand shoal/tidal flat complex. The scoured base of facies C3b beds represents basal-channel erosion surfaces similar to those observed in the outer tidal channels of the German Bight, North Sea (Reineck and Singh, 1980). The northeast-directed paleoflow indicators observed in facies C3b suggest that the unidirectional currents that deposited the facies may have been produced by storm enhanced, offshore-directed currents focused in deeply scoured tidal channels.

The heterolithic beds of subfacies C3c are interpreted as subtidal sand shoal deposits. A strong tidal influence is suggested by the presence of sedimentary structures including lenticular to wavy to flaser bedding, mud-draped wave ripples, and reversing-polarity ripple cross laminations. The components of facies C3c are analogous to lithologies and sedimentary structures observed along shelf-sand shoal transects of modern open-coast tidal flat systems (Reineck and Singh, 1980). Because of the paleogeomorphology of the interpreted depositional environment (situated between shallow-shelf and sandy tidal flat environments) these deposits can be classified as tidally-influenced shoreface deposits. The large-scale clinoform beds observed in facies C3c are interpreted as having been deposited along a sloping tidal-shoreface surface. The ~30 m amplitude on these clinoform beds represent minimum paleo-water depths for the depositional system.

The intercalation of subfacies C3b channel deposits with the clinoform beds of subfacies C3c indicate the two facies were deposited contemporaneously. The overall upward coarsening of subfacies C3c was produced by north-directed progradation of tidal channels and the tidally-influenced shoreface complex into the basin during the time of deposition.
**Interbedded trough cross-stratified and horizontally stratified sandstones (C4)**

Facies C4 is a tabular, 25 to 50 m thick, green-gray sandstone that directly overlies facies C3 with a scoured contact. Facies C4 consists of two interbedded subfacies: C4a) channel-form sandstone and C4b) horizontally-stratified sandstone (Figure 11). Facies C4a dominates the lower 70% of the assemblage and consists of well-sorted, fine- to coarse-grained, green to gray, glauconitic, calcareous sandstone. Individual beds range in thickness from 0.5-1.5 m with cosets up to 6 m thick. Amalgamated bed sets display an overall tabular geometry but locally can form lenticular, convex down, channel-form bodies, hundreds of meters wide when measured perpendicular to paleoflow direction. Sedimentary structures include trough-cross stratification, ripple-cross lamination, herringbone cross-stratification, interference and wave ripples, along with small- to large-scale ripple-bundles (Figure 11). Near the scoured contact with facies C3, beds contain pebble- to cobble-sized mud rip up clasts, coalified wood, and quartz pebbles. The finer-grained beds within this subfacies are more heterolithic and contain abundant internal reactivation surfaces, superimposed ripple cross laminations and flaser-bedded ripples. Paleocurrent indicators show a bimodal and bipolar orientation to the NE-SW (Caputo, 1988).

Facies C4b dominates the upper 30% of the assemblage, and consists of tabular to wedge shaped beds of fine- to medium-grained sandstone. Individual beds are up to 1m thick and locally preserve convex-up upper surfaces. Sedimentary structures include horizontal/low-angle plane-parallel laminations and ripple-cross laminations. Bed surfaces contain asymmetric lunate and straight-crested ripples, ripple-fans, both symmetrical-crested and interference ripples, and primary current lineations. Paleocurrent data collected from current lineations and ripple cross laminations show location specific bimodal orientations that range from NW-SE to NE-SW.

Facies assemblage C4a is interpreted as sub-intertidal tidal channel and sandflat deposits (Reineck et al. 1970). The cross-stratified channel-form sandstones of facies C4a are interpreted as tidal channel deposits. The presence of rip-up clasts, double-mud drapes, internal reactivation surfaces, flaser-bedded ripples, and herringbone cross-
Figure 11. Photographs of facies C4, I-70 West (Section 2). A) Horizontally stratified deposits of C4b interpreted to represent tidal sand-flat deposits. B) Primary current lineations within facies C4b. C) Trough cross stratified tidal channel deposits of facies C4a with organics filling trough bottoms. D) Herringbone cross stratification within facies assemblage C4a. E) Sigmoidal tidal bundles within facies assemblage C4a.
stratification are all diagnostic features of a tidal environment (Boersma and Terwindt, 1981). The abundance of small- and large-scale ripple bundles and vertically-separated, large-scale cross beds with opposite paleocurrent orientations also suggests the presence of strong bipolar currents which are seen in modern ebb-flood subtidal channel systems (Kreisa and Moiola, 1986).

Facies C4b is interpreted as intertidal sandflat deposits. The horizontally stratified sandstones and beds with convex-up upper surfaces are interpreted as having been deposited by upper-plane beds or low-amplitude barforms by unconfined flows in water less than a few meters deep (Allen, 1980). Within the horizontally stratified sandstones the alternation between ripple cross lamination and horizontal laminations is probably representative of the different flow velocities produced during the tidal cycles. The presence of asymmetrical, symmetrical, and interference ripples indicate both unidirectional-current and wave influence on sediment transport common in tidal sandflat environments. Observed ripple-fan complexes indicate a shallowing, and possible macroform emergence at low tide. Within facies C4, the overall up-section change from channel-form sandstones to dominantly horizontally stratified sandstones is interpreted as resulting from a shift of primarily subtidal to intertidal depositional environments.

**Upward fining heterolithic sandstone/mudstone (C5)**

Facies C5 consists of 5-16 m of interbedded brown-green fine-grained sandstones with green mudstones (Figure 12). Sandstones have both lenticular and tabular geometries and are very-fine to fine-grained, with individual beds up to 1.5 m thick. Sedimentary structures in facies C5 sandstones consist of straight crested wave and current ripples, interference ripples, ripple-cross laminations, and horizontal laminations. Sandstones are intercalated with green siltstones and mudstones that become more abundant up section. Mudstones commonly display sand-filled polygonal desiccation cracks and salt hopper casts. Trace fossils include sparse vertical and horizontal burrows as well as large-diameter (up to 50 cm), vertically oriented, (up to 40 cm in depth), convolute laminations that are interpreted as sauropod walking traces (e.g. Lockley et al. 1996). Facies C5 represents the gradational contact between the Curtis and the Summerville Formations.
Figure 12. A) Outcrop photograph of facies C5 intra-tidal flat deposits (between blue and dashed white lines), Last Chance Wash (Section 1). C5 facies represent the transition between the sand-dominated Curtis Formation and the mud-dominated Summerville Formation. B) Ripple cross lamination within facies C5 lenticular tidal channel deposits. C) Straight-crested ripples within facies C5.
The lenticular, ripple-cross stratified sandstones in facies C5 are interpreted as tidal creek deposits, while intercalated tabular horizontally-stratified sandstones and laminated mudstones/siltstones are interpreted as inter-tidal flat deposits. Preserved ripple forms indicate both unidirectional-current, and combined-flow influence on sediment transport, both of which are characteristic of tidal flat environments. Periodic subaerial exposure and evaporitic conditions in facies C5 is suggested by the presence of polygonal shrinkage cracks and localized salt-hopper casts. The low-abundance and diversity of ichnofossils possibly reflects highly stressed paleoenvironmental conditions. The overall upward fining nature of the facies C5 deposits is interpreted to represent a transition from inner sandy to inner muddy tidal flat deposition through time (cf. Howard et. al., 1975). This facies represents the gradational contact between sand-dominated sub-to intertidal deposits of the Curtis Formation and mud-dominated inter- to supra-tidal deposits of the Summerville Formation.

**Summerville Formation**

In the study area the Summerville Formation consists of 30-90 m of mudstone, sandstone, and gypsum (Figure 13). The lower boundary of the Summerville Formation is gradational with facies C5 of the underlying Curtis Formation. Internally, both overall grain size and bed thickness increase up section. The Summerville Formation is unconformably capped by gray mudstones, limestones, and sandstones of the Tidwell Member of the Morrison Formation. The Summerville Formation consists of two generalized lithofacies assemblage including a silty mudstone/sandstone (S1) and a gypsiferous mudstone/sandstone (S2).

**Facies assemblage (S1): Silty mudstone/sandstone**

Facies S1 consists of 30-70 meters of tabular, reddish-brown silty-mudstones intercalated with green to tan sandstones. The red silty-mudstone comprises the bulk of facies S1 across the region. These mudstones are dominantly structureless to laminated with sand-filled polygonal desiccation cracks and localized salt-hopper casts. Sandstones within Facies S1 have dominantly tabular geometries and are very-fine to fine grained, with individual beds up to 3 m thick. In some places, however, sandstone beds display broadly lenticular geometries 0.5-2 m thick and up to 200 m wide. Sedimentary structures
Figure 13. Generalized stratigraphic log of the Summerville Formation showing lithologies, sedimentary structures, and interpreted lithofacies assemblages (S1-S2).
within the tabular beds include interference ripples, asymmetrical wave ripples, horizontal laminations, primary current lineations, and ripple-cross laminations. Sedimentary structures present in the lenticular sand-bodies include trough-cross stratification and ripple-cross stratification. Within facies S1, no trace or body fossils were observed within this study, although localized sauropod walking traces have been identified by others (e.g. Lockley et al. 1996).

Facies assemblage S1 is interpreted to represent a tidal flat/sabkha environment. Tabular sand bodies and mudstones are interpreted to represent tidal flat deposits, whereas the trough-cross stratified lenticular sand bodies with erosional bases were deposited by tidal channels. Preserved ripple forms indicate both unidirectional-current, and combined-flow influence on sediment transport, which are characteristic of tidal flat environments. Periodic subaerial exposure is suggested by the presence of polygonal shrinkage cracks. Evaporitic conditions are inferred by localized salt-hopper casts. The lack of trace fossils suggests that this was an ecologically highly stressed paleoenvironment.

**Gypsiferous mudstone/sandstone (S2)**

Facies S2 consists of up to 10 m of intercalated mudstones, sandstones, and gypsum. This facies overlies facies assemblage S1 in localized regions across the study area. Facies assemblage S2 is dominantly composed of structureless, tabular, reddish-brown mudstones. Bedding plane structures in these mudstones include polygonal desiccation cracks, wrinkle marks, and raindrop impressions (Caputo, 1988). Intercalated with these mudstones are very-fine to medium-grained sandstones and gypsiferous beds. Sandstones have tabular-lenticular geometries and are primarily 1-6 cm thick with occasional thicker lenses up to 60 cm thick. Sedimentary structures within facies S2 sandstones include ripple cross lamination as well as bedding plane structures that include unidirectional and wave ripples. Gypsiferous beds are tabular or consist of isolated to coalesced nodules. Tabular beds are 0.5-1 m thick and increase in abundance and thickness up section where present. These beds are often separated by thin (<0.3 m) deposits of red mudstones. Nodules are hosted in a red mudstone matrix. Individual nodules range from 1-14 cm when measured along their long axis. In places these facies
Figure 14. A) Photograph of gypsiferous beds of the upper Summerville Formation (facies S2) and unconformable contact with the Morrison Formation. Resistant layers are sandstones and bedded/nodular gypsum beds; dark-colored recessive strata are mudstones. B) Photograph of Summerville Formation muddy tidal flat/sabkha deposits of (facies S1) at Cedar Mountain 2 location (Section 7). C) Photograph of upper part of Summerville Formation facies S1 at Cedar Mountain 2 location (Section 7).
display a slight angular unconformity with the overlying Tidwell Member of the Morrison Formation (Figure 4).

Facies assemblage S2 is interpreted to represent a sabkha environment. Tabular sand bodies and mudstones are interpreted to represent tidal flat deposits. Gypsum deposits are interpreted to be deposited within highly evaporitic localized salinas within a sabkha environment.

**Stump Formation, Curtis Member**

The Stump Formation within the Uinta mountain region is subdivided into two formal members including the Curtis Member and the Redwater Member (Pipiringos and Imlay, 1978). The Curtis Member in the Uinta Mountain region is up to 50 m thick (Figure 15) and contains two lithofacies assemblages including a heterolithic sandstone/mudstone assemblage (Sc1), and an interbedded trough cross-stratified and horizontally stratified sandstones assemblage (Sc2) (Figure 16).

**Heterolithic sandstone/mudstone (Sc1)**

Facies Sc1 is characterized by up to 3m of wavy-bedded, medium-grained, glauconitic sandstones interbedded with red and green mudstones. Individual sandstone beds are 1-30 cm thick and contain red and green mud rip-up clasts along with rhythmically-deposited mud-draped ripples (Figure 16). The distribution of this facies assemblage is discontinuous in the Uinta Mountain region and across the study area and occurs primarily as broad lenses up to 3 m thick and km’s wide at the base of the Curtis Member. Where present, this assemblage always directly overlies the Eolian deposits of the Entrada Formation and the boundary between the two defines the J3 unconformity (Eschner and Kocurek, 1986).

Facies assemblage Sc1 is interpreted as having been deposited on intertidal mudflats at the landward edge of a transgressing shallow sea. Sc1 deposits are interpreted as lateral equivalents to the higher energy tidal environments of the channel-form and horizontally stratified sandstones of facies assemblage Sc2 (Eschner and Kocurek, 1986). Tide dominance is suggested by the presence of wavy bedding and mud-draped ripples suggesting alternating current and slackwater conditions as the result of semi-diurnal tidal fluctuations.
Figure 15. Generalized stratigraphic log of the Curtis Member of the Stump Formation in the Uinta Mountain region showing lithologies, sedimentary structures, and interpreted lithofacies assemblages (Sc1 and Sc2).
Figure 16. A) Photograph of herringbone cross stratification within facies Sc2, at Chew Ranch (Section 23). B) Mud-draped ripples in facies Sc1, Island Park 1 location (Section 21). C) Contact between the Entrada Formation and the Heterolithic sandstone/mudstone deposits of facies assemblage Sc1, Island Park 1 location (Section 21).
Trough cross-stratified and horizontally stratified sandstones (Sc2)

Facies assemblage Sc2 consists of up to 30 meters of tabular fine to medium-grained, glauconitic quartzose sandstones. These sandstones are subdivided into two subfacies; Sc2a) channel form sandstones and Sc2b) horizontally stratified sandstones. As a whole, this facies assemblage directly overlies facies assemblage Sc1, or is separated from the eolian deposits of the underlying Entrada Formation by the J3 unconformity (Figure 17).

Subfacies Sc2a consists of up to 30 meters of tabular beds of fine to coarse-grained, green to grey glauconitic sandstones. Sedimentary structures include trough-cross stratification, ripple-cross lamination, herringbone cross-stratification, flaser bedding and straight crested ripples. This unit is dominated by trough-cross stratified beds that range from 0.25 m-1.5 m thick with cosets up to 6 m thick. The base of the channel forms are locally scoured and contain lags of mud chips and chert and quartz pebbles. Paleocurrent data collected from trough forests show a bimodal north-south transport with north-directed dominance (Eschner and Kocurek 1986).

Subfacies Sc2b consists of up to 20 meters of gray to green, fine to medium-grained, horizontally stratified sandstones. Individual beds are tabular to wedge shaped and range in thickness from 0.1 to 1 meter thick. Internally these beds consist of horizontally laminated intercalations of sand, clay, and organic material. In some localities, mud-draped ripples are also preserved. In most places, the horizontally stratified sandstones of subfacies Sc2b are preserved between cosets of subfacies Sc2a.

Facies assemblage Sc2a is interpreted as tidal channel and sandflat deposits. The cross-stratified channel-form sandstones of facies Sc2a are interpreted as tidal-channel deposits. The presence of rip-up clasts, flaser bedding and herringbone cross-stratification are all diagnostic features of a tidal environment (Boersma and Terwindt, 1981). This suggests the presence of strong bipolar currents which are seen in modern ebb-flood subtidal channel systems (Kreisa and Moiola, 1986).

Facies Sc2b is interpreted as subtidal sandflat deposits. The horizontally stratified sandstones are interpreted as having been deposited by upper-plane beds or low-amplitude bar forms by unconfined flows in water less than a few meters deep (Allen, 1982). Within the horizontally stratified sandstones the alternation between horizontal
laminations of sandy clay and organic materials is probably representative of the different flow velocities produced during the tidal cycles.

**Stump Formation, Redwater Member**

The Redwater Member within the study area is up to 30 m thick (Figure 17) and can be subdivided into three lithofacies assemblages including a bioturbated sandstone/mudstone assemblage (Sr1), a laminated black shale assemblage (Sr2), and an upward coarsening hummocky cross stratified sandstone/mudstone assemblage (Sr3) (Figure 18).

**Bioturbated sandstone/mudstone (Sr1)**

Facies assemblage Sr1 disconformably overlies Curtis Member facies assemblage Sc2 and at the base is locally marked by an intensely bioturbated pebbly sandstone containing clasts of quartz, carbonate, and chert as well as brachiopod shells and belemnites. This lithofacies assemblage is up to 8 meters thick and composed of brown fine to medium-grained, highly glauconitic sandstones interbedded with dark grey mudstones. Many of the sedimentary structures within this unit have been masked by intense bioturbation, although in some localities hummocky cross stratification is observed. In terms of vertical grain-size trends, facies Sr1 shows an asymmetrical upward coarsening/upward fining trend that culminates in the laminated black shales of the overlying Redwater Member facies Sr2; See below). Interbedded with facies Sr1 sandstones are 10-20 cm thick coquina beds composed of dominantly ostracod and brachiopod fragments. Facies Sr1 sandstones and mudstones also contain thin-walled articulated brachiopods, belemnites, and age-diagnostic ammonites (*Cardioceras*, *Goliathoceras*) (Figure 5).

Facies assemblage Sr1 is interpreted to represent an up-section transition from shoreface to shelf deposits. The basal pebbly sandstone is interpreted as a transgressive lag deposit formed along a wave-ravinement surface. Marine influence is suggested by the presence of glauconite and the diverse assemblage of marine fauna. The high abundance of ammonites, belemnites, ostracods, brachiopods and echinoderms suggests that this environment was open marine with normal marine salinities. Periodic storm events are indicated by the hummocky sandstones and coquina deposits. The high degree
Figure 17. Stratigraphic log of the Redwater Member of the Stump Formation in the Uinta Mountain region showing lithologies, sedimentary structures, and interpreted lithofacies assemblages (Sr1, Sr2, Sr3).
of bioturbation and preservation of articulated shells suggests that primary deposition was below fair weather wave base with periodic storm reworking. The highly glauconitic and bioturbated nature of these deposits suggest relatively slow sedimentation rates.

**Laminated black shale (Sr2)**

Redwater Member facies assemblage Sr2 overlies the fining upward sandstones of facies assemblage Sr1 and consists of up to 15 meters of very finely laminated black shales with minor thin (<20 cm thick) discontinuous brown fine-grained sandstones displaying hummocky cross stratification (Figure 18). These shales also contain carbonate concretions up to 10 cm in diameter. Up section, sandstone beds increase in abundance and thickness. Palynology samples collected from these shales contained the highest abundance and diversity of palynomorphs, which were dominated by dinoflagellate cyst species.

The laminated black shales of facies assemblage Sr2 are interpreted to represent marine shelf deposits deposited below or near storm wave base. The very finely laminated nature of these deposits suggest that they were laid down in an environment dominated by suspension settling. The presence of micro-hummocky cross-laminated sands suggest that this was a region periodically influenced by storm currents. The high diversity and abundance of dinoflagellate cyst species suggest fully open-marine conditions. When compared with other lithofacies in the stratigraphic interval this assemblage is interpreted as being deposited at the greatest water depths.

**Upward coarsening hummocky cross stratified sandstone/mudstone (Sr3)**

Facies assemblage Sr3 directly overlies the laminated black shales and consists of a 20-30 m thick upward coarsening sequence of mudstone, glauconitic sandstone, and limestone. Within this facies assemblage, sandstones are fine to medium-grained, range in thickness from 0.50m-1m, and become thicker and more abundant up section. The sandstones display both hummocky cross stratification, ripple cross lamination, and symmetrical ripples. In some cases, beds display sole marks including gutter casts and prod marks. Sandstones near the top of the coarsening-upward assemblage are commonly interbedded with 10-50 cm thick beds of 3-5m sandy, oolitic, limestone containing brachiopod and echinoid fossils. Intercalated with the sandstones and
Figure 18. Upward-coarsening Redwater Member facies Sr2 and Sr3, near Finch Draw location (Section 15). Outcrop exposure is ~30 m thick.
mudstones are tabular beds of grey-green mudstone. Within these mudstones palynomorph samples contain an up-section decrease in organic content and species diversity, and an overall increase in woody kerogen content.

Facies Sr2 are interpreted as shallow shelf and shoreface deposits. The abundance of glauconite, marine fossils, and marine palynomorphs all suggest a marine origin. The gutter casts and hummocky cross stratification are indicative of deposits undergoing both unidirectional and oscillatory flow most likely generated by storm events. The alternation of mudstones and hummocky cross stratified sandstones suggest a depositional environment below fair weather wave base and above storm wave base. The up section increase in sandstone thickness and abundance, as well as the presence of intercalated oolitic limestones, indicates an overall decrease in water depth from below to within fair-weather wave base.

SEQUENCE STRATIGRAPHY

The biostratigraphic and sedimentologic data are used here to formulate a sequence stratigraphic model for Curtis, Summerville and Stump formation deposition in the study area. The model helps clarify the stratigraphic architecture of the Middle-Upper Jurassic rocks of eastern Utah and western Colorado as it accounts for the lithological variability of these units that have hampered past regional lithostratigraphic correlations. The model also allows for more detailed paleoenvironmental reconstructions and provides greater insight into the depositional history of the southern part of the Western Interior basin during the Late Jurassic. Additionally, the new model may serve as a guide for sequence-stratigraphic interpretations of other tidally-influenced depositional systems.

Overall, this depositional system is interpreted to represent one unconformably-bound, transgressive-regressive sequence deposited during Oxfordian time. Below, the primary sequence-stratigraphic surfaces, as well as internal systems tracts, are discussed in more detail. The sequence-stratigraphic terms used in the model are derived primarily from Van Wagoner et al. (1988) and Catuneanu (2006).

Basal Sequence-Bounding Unconformity (J3 Unconformity)

The basal sequence boundary is one of the most recognizable boundaries within the study area and is defined as the contact between the eolian strata of the Entrada
Figure 19. Sequence stratigraphic correlation of the Curtis and Redwater members of the Stump Formation in northeastern Utah. See Figure 17 for symbol explanations. Correlations utilizing all measured sections in Uinta Mountains study area are displayed in Plate 1.
Figure 20. Sequence stratigraphic correlation of the Curtis and Summerville formations in east-central Utah. See Figure 17 for symbol explanations. Correlations utilizing all measured sections in San Rafael Swell study area are displayed in Plate 2.
Formation and the overlying tidally influenced deposits of the Curtis Member (Uinta Mountains, Figure 19) and Curtis Formation (San Rafael Swell, Figure 20). This regional surface is erosional with relief up to 20 meters over lateral distances of 100’s of meters to 10’s of kilometers. The boundary is interpreted to represent a lowstand-erosion surface that cut valleys into the underlying Entrada Formation prior to the last major advance of the Jurassic interior seaway. In places, however, this surface was modified by both tidal and wave scour prior to initial sequence deposition. The interpreted tidal reworking of the J3 unconformity surface beneath Curtis and Stump formation facies C1, Sc1, and Sc2, indicate the presence of a superposed tidal ravinement surface (Allen and Posamentier, 1993) at the base of incised valley-fill deposits in both the Uinta and San Rafael Swell regions (Figure 19, Figure 20). Additionally, the lower sequence bounding unconformity is also associated with a superposed wave ravinement surface where the transgressive lag at the base of the Curtis Formation (facies C2) rests directly above the Entrada Formation (Figure 20).

**Transgressive Systems Tract**

The deposits of the transgressive systems tract (TST) consist of the basal tidal and shallow marine deposits of the Curtis and Stump formations in the study area. In the Uinta Mountain region, TST deposits consists of tidal channel/flat, and shallow marine deposits of the Stump Formation Curtis Member (facies Sc1, Sc2, and Sr1). In this area, tidal flat and tidal channel deposits (facies Sc1 and Sc2) vary in thickness and distribution (Figure 19). These tidal facies are interpreted as having been deposited in paleo-valleys during the initial phase of increased accommodation development in the basin. The tidal and shallow marine facies of the Curtis Member are separated by a transgressive lag (previously interpreted as the J4 unconformity) that corresponds to the initial marine ravinement surface in the depositional sequence. An overall fining-upward sequence of Lower Redwater Member shoreface and shallow-shelf deposits (facies Sr1) represents the uppermost TST deposits in the Uinta Mountain region. TST deposits are overlain by laminated black shales of the Redwater Member (facies Sr2, Figure 19). As this facies is interpreted as the deepest-water deposits in the interval, the contact between the shale and the underlying shallow-shelf deposits of the Curtis Member represents the Maximum Flooding Surface (MFS) of the depositional sequence (cf. Posamentier et al., 1988).
In the San Rafael Swell region, TST deposits are represented by the incised tidal-channel sandstones and transgressive-lag deposits (facies C1 and C2) in the lower part of the Curtis Formation (Figure 20). These transgressive deposits were deposited above the lower sequence bounding unconformity during a continued relative increase in basin accommodation during early Oxfordian time.

The TST in central Utah is much thinner than similar deposits to the north, reflecting the more landward position or the region during the Late Jurassic advance of the Jurassic Interior seaway. In the San Rafael Swell region, TST deposits are overlain by laminated marine mudstones of the lower Curtis Formation (facies C3a). In central Utah, the contact between the lower Curtis marine shale and the underlying transgressive lag represents the sequence MFS. This interpretation is supported by paleogeographic reconstructions of the basin that indicate the southern part of the study area was situated near maximum landward advance of the Jurassic Interior seaway during the initial phases of Curtis Formation deposition (Caputo, 1988).

Based on the above interpretation, the MFS not only serves as the boundary between TST and overlying Highstand Systems Tract deposits but it also serves as an approximate time-correlative surface that can be used in regional stratigraphic correlations (see below).

**Highstand Systems Tract**

Highstand systems tract (HST) deposits of the depositional sequence are situated vertically between the Maximum Flooding Surface and the upper sequence-bounding unconformity. In the Uinta Mountain region, the HST consists of the laminated black marine shales (facies Sr2) that coarsen upward into the shallow-shelf deposits of the upper Redwater Member (facies Sr3) (Figure 19). The upward-coarsening nature of these deposits reflects an overall decrease in water depth and filling of available basin accommodation during the north-directed progradation of associated shallow marine depositional systems through time.

In the San Rafael Swell region, HST deposits consist of an upward-coarsening sequence of marine shelf (facies C3a), tidal channel (facies C3b), tidal shoal/shoreface (facies C3c), tidal channel/flat (facies C4, C5), and sabkha (facies S1, S2) deposits (Figure 20). This sequence reflects an overall north-directed progradation of basin
depositional systems through time. Erosion surfaces at the contacts between the shelf and tidal channel facies (facies C3a and C3b) and shoal/shoreface and overlying tidal-channel deposits (facies C3c and C4a) represent regressive erosion surfaces formed by tidal scour during progradation (Reineck and Singh, 1980; Willis and Gabel, 2003). Other than the observed facies stacking pattern, additional evidence for the progradational nature of these deposits is displayed in the clinoform beds of the tidally-influenced shoal/shoreface deposits (facies C3c) in the Curtis Formation (Figure 10). A generalized cross section of the overall facies and sequence stratigraphic architecture of the Curtis and Summerville formations during highstand progradation of the associated depositional systems is shown in Plate 3.

Highstand systems tract deposits in central Utah are much thicker than in the Uinta Mountain region (~130 m vs. ~55 m, respectively). While some of this thickness variation may have been caused by erosional truncation of the upper-most HST deposits to the north by the upper sequence-bounding unconformity, it most likely reflects an overall increase in basin subsidence in central Utah compared to areas to the northeast (see below).

**Upper Sequence Boundary Unconformity (J5 Unconformity)**

The upper sequence boundary in the study area is at the stratigraphic contact between the Summerville/Stump formations and the overlying Morrison Formation. In the San Rafael Swell region this boundary locally displays an angular relationship between the HST sabkha deposits of the Summerville Formation and lacustrine/fluviatile deposits of the Morrison Formation (Figure 3). In the Uinta Mountain region, however, evidence for the unconformable nature of the contact between the Stump Formation and the Morrison Formation is not as straightforward. In the past, the contact between the marine Stump Formation and the marginal/nonmarine deposits of the Morrison Formation has been interpreted as a conformable sequence (Currie, 1998b). In this part of the study area, however, tidal and floodplain facies of the Morrison Formation rest directly above lower shoreface deposits of the Stump Redwater Member (facies Sr3). The lack of a transitional facies assemblage (i.e. upper shoreface deposits) indicates a relative basin-ward shift in depositional environments, and the possible presence of a sequence-bounding unconformity. In addition, palynology samples collected up through
the Stump Formation in the Uinta Mountain region yielded Early-Middle Oxfordian aged
dinoflagellate cyst species. Based on the age of dated ash horizons and charophyte fossils
(see Stratigraphy and Age section above), the basal Morrison Formation is interpreted as
upper-most Oxfordian in age (Kowallis et al., 1998; Shudeck et al., 1998). This suggests
the potential for an unconformity of as much as 2-4 million years in duration between the
two formations.

Sequence Stratigraphic Interpretation

In the San Rafael Swell region, the Curtis and Summerville formations represent
one unconformity-bound depositional sequence that is composed almost entirely of
tidally-influenced deposits (Figure 20; Plate 3. While tidal deposits in other basins have
been interpreted within a sequence-stratigraphic context, they are most commonly
associated with transgressive systems tract estuarine or marginal marine depositional
systems (Dalrymple et al., 1992). The majority of the Curtis and Summerville tidal
deposits, however, are interpreted as being part of the highstand systems tract.

The sequence stratigraphic interpretation of these deposits is strongly dependent
on sedimentological interpretations of lithologies and erosion surfaces within Curtis
Formation facies assemblage C3. For example, the scoured contact between facies
assemblages C3a and C3b separates shallow shelf deposits from overlying tidally-
influenced deposits. While this contact and facies are interpreted here as being associated
with highstand systems tract progradation of open-coast tidal channel/shoreface
depositional systems (Figure 7; Figure 21), a similar juxtaposition of tidal channel and
shallow shelf deposits has in other instances, been interpreted as marking a sequence-
bounding unconformity (Yoshida et al., 1996). The contact also displays the
characteristics of a forced regression produced during a period of falling sea level and the
resulting basin-ward shift in shoreface-tidal deposystems (Posamentier et al., 1992).

Several lines of evidence, however, indicate that the entire Curtis and
Summerville interval above the basal flooding surface belongs within the highstand systems tract. To begin, in some locations in the study area, facies C3a grade upwards
into facies C3c, indicating that the erosion surface at the base of facies C3b is a localized
scour surface. In addition, palynology samples collected from both facies C3a and facies
C3c above the scoured contact, contain identical age-diagnostic dinoflagellate species
(Figure 20 Section 12, Dry Mesa; Appendix B). Collectively, these relationships indicate relatively continuous deposition in the lower part of the Curtis Formation and are arguments against the presence of a sequence bounding unconformity at the base of facies C3b.

The possible forced regression interpretation of the facies C3a/C3b contact is also unlikely given the interpreted conformable nature of the overlying Curtis-Summerville stratigraphic interval (Caputo, 1988; Peterson, 1988). In most described examples, forced regression deposits are interpreted as being associated with periods of decreasing accommodation within a basin (Catuneanu, 2006). However, the substantial thickness (~100 m) of the conformable Curtis and Summerville interval overlying the contact suggest that deposition occurred during a period of positive accommodation development within the basin.

As stated above, the contact between facies C3a and C3b is interpreted scour that occurred at the base of deep tidal channels basin-ward of a prograding open-coast sand shoal/tidal flat complex. The observed intercalation of facies C3b channel conglomerates and C3c clinoform sandstones indicate the prograding tidally-influenced shoal/sandflat complex and the associated off-shore subtidal channels were contemporaneous depositional systems. Similar modern off-shore tidal channel and shoal/sandflat depositional systems have been described from the North Sea (Reineck and Singh, 1980), and offshore tidal channels incising shelf sediments have also been identified in the Indus and Yellow river deltas (Hori et al. 2002; Kuehl et al. 1989). Similar contact relationships observed between facies C3a and C3b have also been reported from the progradational tidal delta deposits of the Upper Cretaceous Sego Sandstone in eastern Utah (Willis and Gabel, 2003).

REGIONAL CORRELATIONS

A test of the sequence stratigraphic framework outlined above is the regional continuity of the proposed sequence components. This is of particular importance because the lithological variations displayed within the Curtis-Summerville-Stump stratigraphic interval preclude simple lithostratigraphic correlations. Because the lithological changes within the studied Jurassic stratigraphic interval occur beneath the Cretaceous-Eocene rocks of the Uinta basin, petroleum industry bore-hole gamma-ray
Figure 21. Regional sequence stratigraphic correlation of the Curtis, Summerville, and Stump formations between the San Rafael Swell and Uinta Mountain regions utilizing outcrop measured sections and petroleum industry borehole data. See text for explanation.
logs were employed to aid in the regional correlation. To facilitate the stratigraphic
correlation between the outcrop and subsurface, outcrop gamma-ray logs were
constructed for measured stratigraphic sections in the study area using a hand-held
gamma spectrometer (i.e. Slatt et al., 1995). Outcrops sections were trenched to
unweathered bedrock and total gamma ray count-levels were recorded at 30 cm vertical
intervals. Figure 21 shows a regional correlation of the Curtis-Summerville-Stump
stratigraphic interval between the San Rafael Swell and the Uinta Mountain region using
outcrop lithological/gamma ray logs and industry bore-hole gamma log data.

In order to interpret the internal sequence stratigraphic relationships across the
region, the maximum flooding surface identified in surface outcrops was correlated to the
subsurface. The MFS by definition defines the contact between the transgressive and
highstand systems tracts (Posamentier et al., 1988), and provides an approximate time-
correlative horizon from which overall sequence geometry can be discerned. The MFS
provides a convenient regional marker horizon because the high gamma-ray (GR)
readings associated with it (owing to the high clay/organic content of facies C2 and Sr2)
are easily identified in the subsurface well-log data (Figure 21). In the San Rafael Swell
region the maximum flooding surface is interpreted as the highest GR reading
immediately below the C-shaped gamma log profile associated with the sands of facies
C3 and C4. Within the Uinta Mountain region the maximum flooding surface is
interpreted as the highest gamma ray reading within the lower half of the interval (Figure
21).

Following the regional correlation of the MFS, both the upper and lower
sequence-bounding unconformities were identified in the subsurface logs. This was
accomplished by comparing the outcrop gamma-ray signature of lithologies across each
unconformity with nearby borehole logs, and consistently correlating the observed
signature between wells. Regional correlation of the MFS and both upper and lower
sequence-bounding unconformities allows the internal architecture of the depositional
sequence to be evaluated.

The transgressive deposits across the study area overall thicken basinward from <
8 m thick in the San Rafael Swell region to 30 m thick in the Uinta Mountain region. In
the north, the lowermost TST deposits of the Stump Formation (facies Sc1, Sc2) thicken
because of their deposition within incised valleys overlying the lower sequence-bounding
unconformity (Figure 21). The top of these deposits are easily recognizable in the subsurface because of the gamma-ray increase in deposits above the initial wave ravinement surface (previously termed the J4 unconformity) overlying the lower Curtis Member facies Sc1 and Sc2. Transgressive marine sandstones and mudstones (facies Sr1) rest above this initial marine flooding surface in the northern part of the study area. Stump Formation TST deposits correlate to the south with the incised tidal channel and transgressive lag deposits (facies C1 and C2) at the base of the Curtis Formation in the San Rafael Swell region. These deposits are indicated by the low GR readings observed between strata of the Entrada Formation and the MFS.

The highstand systems tract across the region makes up the majority of the overall thickness of the sequence and records the basinward progradation of Curtis-Summerville-Stump marine/marginal marine depositional systems. In the north, both outcrop and subsurface GR logs record three upward coarsening intervals above the MFS. The uppermost parasequence, however, is truncated by the upper sequence bounding unconformity. These intervals, which consist of facies Sr2 and/or Sr3, are interpreted as recording shallowing/deepening trends associated with shoreface progradation and subsequent regional increases in relative sea level. As such, each upward coarsening package can be classified as a parasequences that is capped by a marine flooding surface (Van Wagoner et al., 1990).

Each HST parasequence identified in the northern part of the study area can be correlated to the south with differing degrees of confidence. Wave influenced deposits (facies Sr3) in HST parasequences 1 and 2 can be traced as far south as the Fed 22-1 well before they transition into progradational tidal-shoreface/tidal flat deposits (facies (C3c/C4/C5)) in the Jack Canyon 1 well (Figure 21). South of the Jack Canyon 1 well, the GR signature of the lower two parasequences is not easily discerned. This may reflect a dampening of the effects of the relative sea level following parasequence 1 deposition due to an increase in overall sediment supply in the sand-dominated Curtis tidally-influenced depositional system. However, a slight lithological fining observed within the Curtis Formation sandstones in the Sunnyside 1 well and Humbug Canyon outcrop GR profiles may correspond to this flooding event and delineate the two lower HST parasequences in the San Rafael Swell region (Figure 21).
The uppermost HST parasequence in the study area can be correlated with confidence as far south as the Jack Canyon 1 well, and with some speculation to the Sunnyside 1 well. In the Jack Canyon 1 well, shoreface deposits (facies Sr3) are separated from underlying intertidal mudstone and sandstone (facies C5) by the uppermost flooding surface. South of the Jack Canyon, shoreface sands of the upper parasequence transition into tidal flat and sabkha deposits of the upper Curtis and Summerville formations (facies C5 and S1).

Summerville Formation tidal flat and sabkha deposits (facies S1 and S2) overlie the shoreface and tidal flat deposits of the Curtis Formation in the southern part of the study area, and culminate the overall progradational trend of the HST. North of the Jack Canyon 1 well, the entire Summerville Formation, as well as the upper parts of the third HST marine parasequence are removed beneath the upper sequence bounding unconformity (J5 unconformity) (Pipiringos and O’Sullivan, 1978). This results in an SW-NE decrease of ~50 m in the overall thickness of the HST deposits in the study area. Because underlying Jurassic rocks in the region display this same overall decrease in thickness to the northeast (Hintze, 1988; Caputo, 1988), the observed thickness variation most likely reflects an overall increase in basin subsidence in central Utah compared to areas to in the eastern Uinta Mountain region.

PALEOGEOGRAPHIC RECONSTRUCTIONS

The sequence stratigraphic framework outlined above permits a detailed paleogeographic reconstruction of the southern part of the Western Interior basin during the Late Jurassic. Figure 22 depicts the spatial evolution of Curtis, Summerville, and Stump depositional systems throughout the Oxfordian, based on the interpreted distribution of lithofacies assemblage identified in the studied stratigraphic interval. The development of a lowstand unconformity above the eolian and erg-margin deposits of the Entrada Formation during the late Callovian provided the initial framework for Curtis, Summerville, and Stump formation deposition (T1, Figure 22). The initial phase of early Oxfordian sea-level rise, resulted in TST tidally influenced valley-fill and marine-shelf deposition of the Curtis Member in the northern part of the study area (T2, Figure 22). Transgressive systems tract deposition continued as the seaway advanced to the south,
Figure 22. Paleogeographic reconstructions of Curtis, Summerville, and Stump depositional systems in the study area during the Oxfordian. T1: Callovian Lowstand unconformity development above the eolian and erg-margin deposits of the Entrada Formation. T2: Initial TST tidal and shelf deposits. T3: Maximum transgression across the region. T4: Progradational maximum within HST Parasequence 2. T5: Flooding event at the base of highstand parasequence 3. T6: Regional development of the J5 unconformity. Dashed line depicts the approximate northern boundary limit of Summerville deposition. Colors and cross-section correspond to Figure 21.
resulting in the development of a tidal/wave ravinement surface on lower-most Curtis Formation tidal-channel and transgressive lag deposition in central Utah.

Maximum transgression of the seaway resulted in marine shelf deposition as far south as the southwestern part of the present-day San Rafael Swell (T3, Figure 22). This was followed by overall north-directed progradation of Curtis, Summerville, and Stump depositional systems during HST deposition (T4, Figure 22). Overall progradation was punctuated by two minor flooding events (the second of which is depicted in T5, Figure 22), that resulted in the development of the three parasequences identified across the region. Finally a drop in relative sea level across the region resulted in the development of the upper sequence-bounding unconformity (J5) (T6, Figure 22).

CONCLUSIONS

New biostratigraphic data collected as part of this study redefines the age of the Curtis, Summerville and Stump formations in Utah and NW Colorado from their current late-middle Callovian age to a lower-middle Oxfordian age. This data, when combined with the age of the overlying Morrison Formation, brackets the age of Curtis/Summerville and Stump deposition from early to late Oxfordian time (~161-155 ma). Consequently, this new age data shows that the lithologically distinct Curtis, and Summerville formations of east-central Utah were deposited contemporaneously with the Stump Formation in northern Utah and northwest Colorado.

As a result of the new age control presented above, sequence stratigraphic concepts were used in order to show the stratigraphic relationship between tide-dominated deposits of the Curtis and Summerville formations and the wave-dominated deposits of the Stump Formation. These units are shown to represent one unconformably-bound transgressive-regressive sequence recording the last major pulse of the Jurassic Interior Seaway during the Oxfordian. Within the highstand systems tract three basin wide parasequences were identified using outcrop and subsurface gamma logs along with the detailed sedimentology. This newly developed sequence stratigraphic model helps to clarify the stratigraphic architecture of the Middle-Upper Jurassic units of eastern Utah. This new data allowed for the construction of detailed paleoenvironmental reconstructions showing the depositional systems of the southern margin of the Jurassic Interior seaway throughout the Oxfordian. As a result, these reconstructions have lead to
a better understanding on the timing and development of the Western Interior Basin throughout the Late Jurassic. Additionally, the new sequence stratigraphic model presented within this paper may serve as a model for other tidally-influenced depositional systems.
REFERENCES


Pacific Coast Paleogeography Symposium 2: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 33-70.


Howard, J.D., and Reineck, H.E., 1975, Comparison of physical and biogenic sedimentary structures of a marine high energy and a marine "zero energy" coast: International Congress on Sedimentology, v. 9, Theme 6.


APPENDIX A. Detailed Measured Sections (outcrop gamma logs where applicable) and their geographic coordinates. Sedimentology was documented at less than a 10 cm resolution and gamma log data points were gathered at 30 cm intervals.

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<th>Longitude</th>
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EXPLANATION OF SYMBOLS FOR SECTIONS AND PLATES

SCALE

--- San Rafael Swell Sections 1-14 p stands for Pebble Conglomerate.

--- Uinta Mountain Sections 15-25 p stands for Limestones (packstones & grainstones)

FORMATIONS AND UNCONFORMITIES

--- J5 Unconformity Surface
Jm  Morrison Fm.
Js  Summerville Fm.
Jsr Stump Fm./ Redwater Mbr.
--- J4/ Initial Flooding Surface
Jsc Stump Fm./ Curtis Mbr.
Jc  Curtis Fm.
Je  Entrada Fm.
--- J3 Unconformity Surface

SEQUENCE STRATIGRAPHY

HST  Highstand Systems Tract
TST  Transgressive Systems Tract
MFS  Maximum Flooding Surface

SEDIMENTARY STRUCTURES

--- Rip Up Clasts
--- Plane parallel lamination
--- Ripple cross lamination
--- Hummocky cross-stratification
--- Trough cross-stratification
--- Vortex Ripples
--- Desiccation Cracks
--- Sigmoidal Tidal Bundles
--- Flaser bedding
--- Wavy bedding
--- Lenticular bedding
--- Bipolar bimodal cross-stratification
--- Ripple Bundles
--- Glauconite
--- Ooids

BIOSTRATIGRAPHIC SAMPLES

--- Ammonite Fossil Collected
p  Palynology Sample Collected
--- Belemnite Fossil Collected
SECTION #3 “Moore Cutoff”
SECTION #5 “San Rafael River”
SECTION #7 “Cedar Mountain 2”
SECTION #9 “Humbug Canyon”
SECTION #10 “Price River”
SECTION #12 “Dry Mesa”
SECTION #15 “Finch Draw”
SECTION #16 “Irish Canyon”
SECTION #17 “Deerlodge Park”
SECTION #19 “Red Fleet”
SECTION #20 “Island Park”
SECTION #21 “Island Park 1”
SECTION #22 “Orchid Draw”
SECTION #23 “Chew Ranch”
APPENDIX B. Complete list of all spores, pollen, and microplankton collected from Red Fleet #19, Deerlodge Park #18, Dry Mesa #12, Chew Ranch #23, Price River #10 and Hanna #25 sample sites. Each sample collected was also analyzed for kerogen content, species diversity, thermal alteration index, age determination, HCL reaction, and kerogen distribution which are shown below.

EXPLANATION FOR PALYNOLGY CHARTS

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<td>Rare, less than 6 specimens/slide</td>
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<tr>
<td>F</td>
<td>Frequent, 6 to 15 specimens/slide</td>
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<tr>
<td>C</td>
<td>Common, 16 to 30 specimens/slide</td>
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**RED FLEET**

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<td>DP20</td>
<td>0.3-0.4</td>
<td>0%</td>
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<td>80%</td>
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<td>Weak</td>
</tr>
<tr>
<td>DP13</td>
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<td>0%</td>
<td>25%</td>
<td>75%</td>
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</tr>
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<td>DP8.4</td>
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<td>80%</td>
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<tr>
<td>DP2.3</td>
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<td>0%</td>
<td>30%</td>
<td>70%</td>
<td>Fair</td>
<td>Weak</td>
</tr>
</tbody>
</table>

Kerogen Content

Species Diversity

Paleoenvironment
## DRY MESA

<table>
<thead>
<tr>
<th>Spore/Pollen</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CM 57 m</td>
</tr>
<tr>
<td>Microplankton</td>
<td></td>
</tr>
</tbody>
</table>

### Microplankton
- Algae
- Cyanobacteria
- Diatoms

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indeterminate (Undifferentiated)</td>
</tr>
</tbody>
</table>

- CM 57 m: R, R
- CM 54 m: R, R
- CM 49 m: R
- CM 48 m: R
- CM 39 m: R, F
- CM 27 m: R
- CM 15 m: A, A, R, A
- CM 12 m: A
- CM 6 m: A
- CM 3 m: A

- R: Present
- F: Fossils
- A: Absent
<table>
<thead>
<tr>
<th>Age</th>
<th>Sample</th>
<th>T.A.I.</th>
<th>Amorphous</th>
<th>Cuticular</th>
<th>Woody/Inertinite</th>
<th>Organic Recovery</th>
<th>HCl Reaction</th>
<th>Kerogen Content</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Indeterminate</td>
<td>DM 57 m</td>
<td>0.3-0.4</td>
<td>70%</td>
<td>15%</td>
<td>15%</td>
<td>Trace</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>DM 54 m</td>
<td>0.3-0.4</td>
<td>50%</td>
<td>25%</td>
<td>25%</td>
<td>Trace</td>
<td>Weak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 49 m</td>
<td>0.3-0.4</td>
<td>30%</td>
<td>20%</td>
<td>50%</td>
<td>Trace</td>
<td>Weak</td>
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<tr>
<td>Late Jurassic</td>
<td>DM 39 m</td>
<td>0.3-0.4</td>
<td>10%</td>
<td>20%</td>
<td>70%</td>
<td>Trace</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>(Undifferentiated)</td>
<td>DM 27 m</td>
<td>0.3-0.4</td>
<td>5%</td>
<td>5%</td>
<td>90%</td>
<td>Trace</td>
<td>Moderate</td>
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<tr>
<td>Early to Middle</td>
<td>DM 15 m</td>
<td>0.3-0.4</td>
<td>0%</td>
<td>20%</td>
<td>80%</td>
<td>Fair</td>
<td>None</td>
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</tr>
<tr>
<td>Oxfordian</td>
<td>DM 12 m</td>
<td>0.3-0.4</td>
<td>10%</td>
<td>20%</td>
<td>70%</td>
<td>Trace</td>
<td>Weak</td>
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</tr>
<tr>
<td></td>
<td>DM 6 m</td>
<td>0.3-0.4</td>
<td>20%</td>
<td>30%</td>
<td>50%</td>
<td>Good</td>
<td>None</td>
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</tr>
<tr>
<td></td>
<td>DM 3.5 m</td>
<td>0.3-0.4</td>
<td>15%</td>
<td>15%</td>
<td>70%</td>
<td>Good</td>
<td>None</td>
<td></td>
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<table>
<thead>
<tr>
<th>Species Diversity</th>
<th>Palaeoenvironment</th>
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</thead>
<tbody>
<tr>
<td>DM 57 m</td>
<td>0 0</td>
</tr>
<tr>
<td>DM 54 m</td>
<td>0 0</td>
</tr>
<tr>
<td>DM 49 m</td>
<td>0 0</td>
</tr>
<tr>
<td>DM 39 m</td>
<td>4 0</td>
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<tr>
<td>DM 27 m</td>
<td>5 0</td>
</tr>
<tr>
<td>DM 15 m</td>
<td>13 12</td>
</tr>
<tr>
<td>DM 12 m</td>
<td>10 5</td>
</tr>
<tr>
<td>DM 6 m</td>
<td>17 14</td>
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<tr>
<td>DM 3.5 m</td>
<td>12 17</td>
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DRY MESA
<table>
<thead>
<tr>
<th>Sample</th>
<th>Hanna 29 m</th>
<th>Chew Ranch 29 m</th>
<th>Price River 17 m</th>
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<tbody>
<tr>
<td>Age</td>
<td>Early to Middle</td>
<td>Oxfordian</td>
<td></td>
</tr>
<tr>
<td>Common Pollen, Spores and Microplankton Sampled</td>
<td>(500X Magnification)</td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>Geiselodinium paeminosum</td>
<td>Murospora bicollateralis</td>
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<tr>
<td>Lycopodiumsporites irregularis</td>
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<tr>
<td>Ellipsoidictyum cinctum</td>
<td>Atopodinium prodatum</td>
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<tr>
<td></td>
<td>Stephanelytron redcliffense</td>
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<tr>
<td></td>
<td>Acanthaulax senta</td>
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<tr>
<td></td>
<td>Ctenidodium ornatum</td>
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<td></td>
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<tr>
<td></td>
<td>Callialasporites triangularis</td>
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<td>Image</td>
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<tr>
<td>1st row</td>
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<tr>
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<td>Wanea fimbriata</td>
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<td>Podocarpidites epistratus</td>
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<td>2nd row</td>
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<td></td>
<td>Araucariacites asutralis</td>
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<td>Tubotuberella dangeardi</td>
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<td></td>
<td>Cerebropollenites mesozoicus</td>
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<tr>
<td>3rd row</td>
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<td>Gonyaulacysta jurassica</td>
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<td>Callialasporites dampieri</td>
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<td>Sentusidinium villersense</td>
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<tr>
<td>Magnification</td>
<td>Image 1</td>
<td>Image 2</td>
<td>Image 3</td>
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<tr>
<td>Deltoidospora sp.</td>
<td>Exesipollenites tumulus</td>
<td>Classopolis classoides</td>
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<tr>
<td>Lithodinia deflandrei</td>
<td>Osmundacidites wellmanii</td>
<td>Undifferentiated Bisaccate</td>
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<tr>
<td>Micrhystridium sp.</td>
<td>Sirmiodiniopsis orbis</td>
<td>Sentusidinium riolti</td>
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</tr>
</tbody>
</table>
Ctenidodinium ornatum  Sentusidinium verrucosum  Distalanulisporoites perplexus

Lycopodiumsporites subrotundus  Pareodinia ceratophora  Rynchodiniopsis cladophora

Cleistosphaericium polyacanthum  Maumia verrucata  Scriniodinium crystallinum
Plate 1. Sequence stratigraphic correlation of the Curtis and Redwater members of the Stump Formation in northeastern Utah.
Plate 3. Generalized depositional-dip cross section of Curtis and Summerville formation highstand systems tract architecture, northern San Rafael Swell region.