Fluvial systems of the Upper Jurassic Morrison Formation, northern Beartooth and Gallatin Ranges, southwest Montana
by Jonathan Todd Cooley

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
The Upper Jurassic Morrison Formation of southwest Montana contains dinosaur remains discovered by paleontologists from the Museum of the Rockies in Bozeman, Montana. Analysis of sedimentology and alluvial architecture suggests the sediments which contain these bones are the deposits of a northeast flowing, low gradient, mud-and-sand dominated anastomosed fluvial system. Characteristic deposits found in the Morrison include low width-to-thickness ratio channel deposits encased in extensive overbank-derived mudstone, crevasse channel and splay deposits, and coal-and-back swamp deposits.

Morrison deposits compare closely with deposits of modern anastomosed fluvial systems, as well as with ancient deposits interpreted as having been deposited by anastomosed fluvial systems. Ancient fluvial channels in the Morrison were laterally stable and changed position through the process of avulsion. This, combined with the delivery of fine-grained, suspended sediment to the mid and distal floodplain through crevasses in levees, resulted in high overall mudstone-to-sandstone ratios and isolated channel deposits. Taphonomic analysis of a bone bed contained within a channel sandstone suggests the fluvial system may have been subject to rapid fluctuations in discharge.

FLUVIAL SYSTEMS OF THE UPPER JURASSIC MORRISON FORMATION, NORTHERN BEARTOOTH AND GALLATIN RANGES, SOUTHWEST MONTANA

by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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For Ward, who loved rocks.

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ABSTRACT

The Upper Jurassic Morrison Formation of southwest Montana contains dinosaur remains discovered by paleontologists from the Museum of the Rockies in Bozeman, Montana. Analysis of sedimentology and alluvial architecture suggests the sediments which contain these bones are the deposits of a northeast flowing, low gradient, mud-and-sand dominated anastomosed fluvial system. Characteristic deposits found in the Morrison include low width-to-thickness ratio channel deposits encased in extensive overbank-derived mudstone, crevasse channel and splay deposits, and coal-and-back swamp deposits.

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INTRODUCTION

Purpose

The goal of this study is to determine the depositional environment of the Upper Jurassic Morrison Formation in the northern Gallatin and Beartooth Ranges of southwest Montana. This includes determination of the paleogeographic setting during Morrison deposition, and types of depositional systems and environments in which Morrison sediment was deposited. More specifically, questions to be addressed in this study include: 1) Which types of depositional environments characterized the Morrison alluvial depositional systems? 2) Which alluvial architecture models compare most closely with the Morrison strata? 3) What were the hydrodynamic characteristics of the specific processes of sediment transport and deposition at work within these systems?

Determining depositional environment is important for two reasons. First, in the last three years the Museum of the Rockies has found numerous dinosaur remains in the Morrison Formation in the study area. Yet to date, no work has been done on the paleoecology of these dinosaur sites. A detailed analysis of the depositional environments and sedimentology of these sites will provide information pertinent to understanding Late Jurassic dinosaurs and the ecosystems they inhabited. Second, this study will allow paleoenvironmental characteristics of dinosaur sites in southwest Montana to be compared with other sites, regional and international, providing a better understanding of dinosaur ecology. Similar studies of Late Cretaceous dinosaur nesting sites in west-central Montana (Lorenz and Gavin, 1984) have provided valuable information concerning dinosaur behavior (Horner, 1987). Additionally, sedimentologic studies focusing on deciphering the depositional setting of Morrison strata have recently been conducted directly to the west (Malone, 1991), and to the north (Meyers and others, 1992) of the study area. This study provides information that will complement these studies and broaden the understanding of Late Jurassic depositional systems in southwest Montana.

By determining the hydrodynamic characteristics of sediment transport and delivery processes, the study addresses a long standing question concerning the Morrison Formation in Montana. Precisely how were the sediments that comprise the Morrison delivered? Peterson (1966) noted a lack of coarse-grained channel bodies and an abundance of mudstone in deposits he interpreted as fluvial. This led to the proposition that much of the mudstone originated as ash fall. This inference, however, was not supported by exhaustive petrographic work by Suttner (1969), who proposed that Morrison fluvial systems were of such low gradient that coarse sand facies were not formed. This study is focused on an area where coarse-grained sandstone bodies, such as those sought by Peterson (1966), crop out. Thus, understanding the origin of these sandstone bodies and the physical processes that linked them to the fine-grained sediments at the time of deposition are primary objectives of this study.

Study Area

Exposures of Jurassic rocks exist along the north flank of the Beartooth and Gallatin ranges (Figure 1) in southwest Montana. The Morrison Formation is exposed in folds produced by late Mesozoic and early

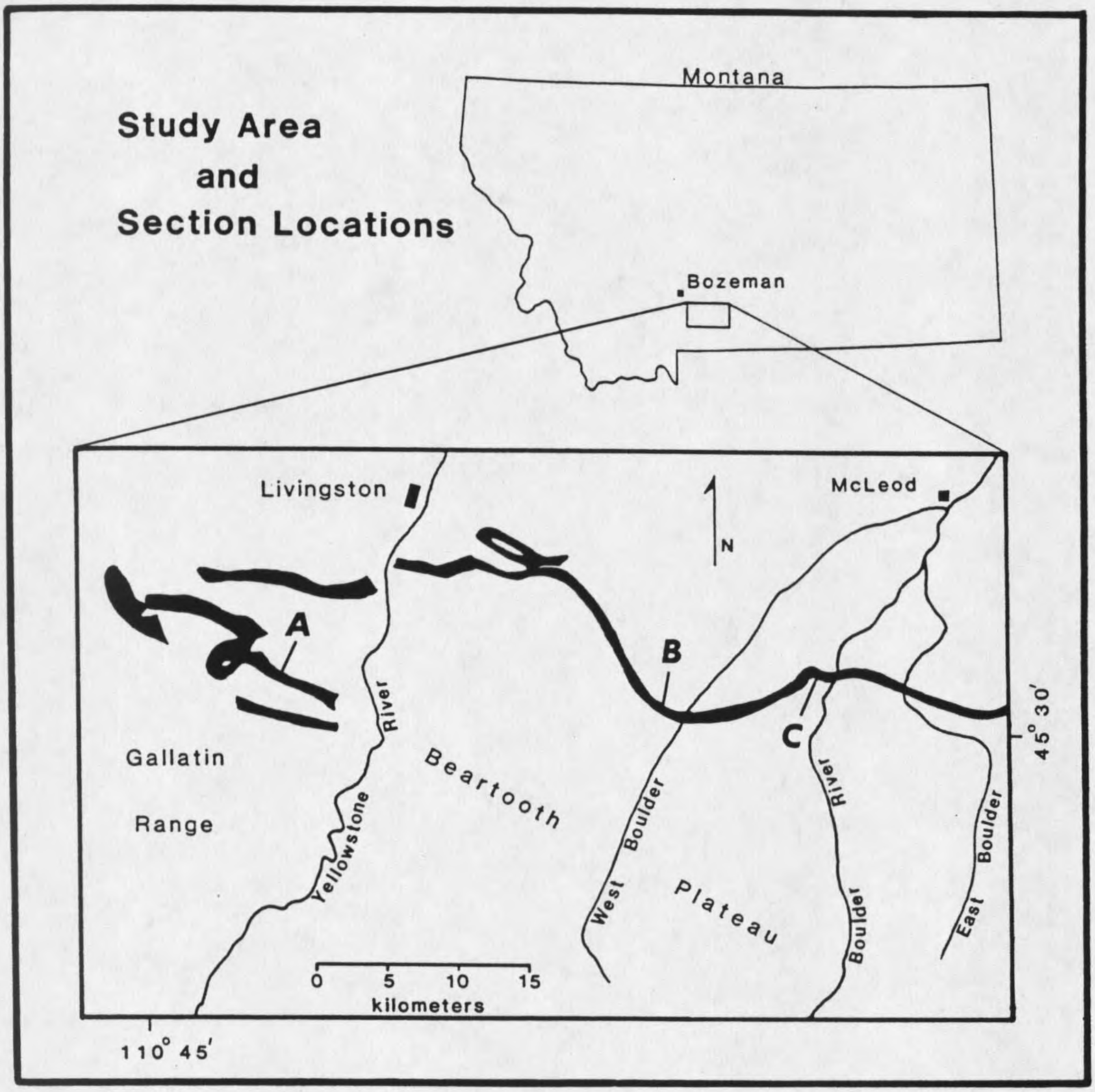

Figure 1. Map of study area, showing location of measured sections and extent of Jurassic rock. A-Strickland Creek (NW1/4, Sec. 29, T3S, R9E, Chimney Rock quad., Mt.), B-West Boulder River (SE1/4, Sec. 26, T3S, R9E, Mt. Rae quad., Mt.), C-Boulder River (NE1/4, Sec. 27, T3S, R12E, McLeod Basin quad., Mt). Adapted from Ross and others, 1955.

Cenozoic uplift. Locations for measured sections were chosen based on quality of exposure and proximity to the Museum of the Rockies quarry. The study area contains three measured stratigraphic sections (A-C, Figure 1).

The Strickland Creek section (section A, Figure 1) is the site of the Museum of the Rockies quarry. The quarry exposes an otherwise covered part of section A. Measurement of a section through the quarry places the bone-bearing unit in its proper stratigraphic context.

The West Boulder River section (section B, Figure 1) contains laterally continuous outcrop of the upper Morrison Formation that was exposed in landslide scarps. In addition, this section provides sedimentologic and stratigraphic information between the Strickland Creek and Boulder River sections.

The Boulder River section (section C, Figure 1) was chosen because it provides excellent lateral exposure of Morrison strata and contains a dinosaur fauna similar to the Strickland Creek section. The presence of dinosaur bones in the Boulder River section allows depositional environment interpretations to be directly associated with dinosaur remains. The majority of the data used to interpret depositional environment was gathered at the Boulder River section.

MORRISON FORMATION

Local and Regional Stratigraphic Context

Previous sedimentologic, stratigraphic, and paleontologic studies of the Morrison Formation and its equivalents, both regional (Imlay, 1952; Moberly, 1960; Walker, 1974; Peterson and Turner-Peterson, 1987), and local (Suttner, 1969; Malone, 1991), concluded that the Morrison Formation in Montana is entirely non-marine and almost entirely fluvial in origin, with lacustrine and eolian processes playing minor roles. In Montana, the Upper Jurassic Morrison Formation records the Late Jurassic onset of terrestrial sedimentation, which followed the rapid northward withdrawal of the Middle Jurassic Sundance Sea (Imlay, 1952). These non-marine conditions continued until transgression of the Cretaceous Western Interior seaway in Albian time.

The Morrison Formation in Montana consists of generally poorly exposed, interbedded mudstone and lenticular sandstone bodies, and is recognized largely by stratigraphic position. These strata overlie the marine Upper Jurassic Ellis Group and are overlain by resistant basal Cretaceous sandstone and conglomerate. The Morrison is correlative with the Kootenay Formation north of the Canadian border. The Kootenay interfingers with the marine Fernie Group farther north (Walker, 1974). The Fernie Group is the only Morrison-equivalent marine deposit known in North America (Walker, 1974), with the possible exception of marine beds known from well logs in the Williston Basin (Francis, 1957). In eastern Idaho and western Wyoming, the Morrison appears to be correlative with the lower Ephraim Formation of the Gannett Group based on biostratigraphy

(Eyer, 1969) and petrographic work by Furer (1970).

The Morrison Formation in the study area, and to the north and west, rests conformably on glauconite-bearing sandstone beds deposited by the retreating Sundance Sea (Walker, 1974; Malone, 1991). This glauconitic, cross-bedded quartz sandstone is known regionally as the Swift Formation and is the uppermost member of the marine Ellis Group (Cobban, 1945). The Ellis Group is correlative with the San Rafael Group in Utah, Stump Sandstone in eastern Idaho (Furer, 1970), and Sundance Formation of Wyoming (Imlay, 1952).

The Morrison is overlain by the Kootenai Formation in Montana. The Kootenai Formation is an equivalent of the Cloverly Formation of central Wyoming and south-central Montana. Both the Cloverly and Kootenai contain a basal, black chert clast-bearing sandstone or conglomerate (Moberly, 1960; Suttner, 1969), which is in unconformable contact with the underlying, poorly indurated mudstones of the Morrison. The precise amount of time represented by this unconformity is unknown.

Age

Until recently the age of the Morrison Formation was based on biostratigraphy using vertebrate and invertebrate fossils with broad ranges (Kowalis and others, 1991). This led to much controversy, as ages ranging from Oxfordian to Neocomian have been proposed for the Morrison (Simpson, 1926; Baker and others, 1936; Stokes, 1944; Yen, 1952; Imlay, 1980). Recent $^{40}Ar/^{39}Ar$ dates obtained from bentonites in the Morrison on the Colorado Plateau, however (Kowalis and others, 1991), constrain most of the formation to the Kimmeridgian and Tithonian (153 to 145 Ma ± 1-2

Ma). Unfortunately, this does not resolve whether the Jurassic/Cretaceous boundary lies at the upper contact of the Morrison, because the youngest dated sample was taken more than 20 m below the top of the Morrison.

The age of the Morrison Formation in Montana is not constrained by radiometric dates, although a Late Jurassic-Early Cretaceous age has been tentatively proposed for the upper Morrison of the Big Horn Basin in Wyoming, based on magnetostratigraphy (Swierc, 1990). Indeed, it seems likely that a formation with such great areal extent could be time transgressive; a concept that has been previously noted (Bowman and others, 1986). Despite the lack of age data, the Morrison Formation in southwest Montana is generally considered to be Late Jurassic in age, with the Jurassic/Cretaceous boundary conveniently placed at the contact between the Morrison and the Kootenai.

METHODS

Measured Sections

Vertical stratigraphic sections were measured in areas of best exposure (Figure 1). Measurements were made at all three localities using a Jacobs Staff and standard techniques of description (Tucker, 1982, p. 9-19). All outcrops between measured sections were walked to search for lithofacies exposure. Lithofacies are classified using Miall's (1985) scheme, and therefore have only a hydrodynamic interpretation associated with them.

Architectural Element Analysis

The distribution and interconnectedness of alluvial sandbodies within finer-grained deposits has been termed "alluvial architecture" (Allen, 1978, Leeder, 1978). This concept has been further developed and formalized as an interpretive method, and labeled "architectural element analysis" by Miall (1985). Architectural elements (original term, Allen, 1963) were defined by grain size, types of bedforms present, internal lithofacies sequence and, most critically, by external geometry. The combination and distribution of these elements within the deposit were used to interpret depositional environment because architecture reflects processes occurring on the scale of floodplain or basin, and this is the scale on which fluvial styles are recognized. Stratigraphic sections were measured not only to record vertical changes in lithofacies and allow the application of Walther's law, but to serve as a framework for recording lateral lithofacies changes. This then allowed the construction of architectural elements. The analysis and interpretation of these elements is the next step towards interpretation of depositional environment. Architectural elements constructed from lithofacies described in the Morrison Formation can be compared to various models as well as other studies which have used this method. These will be discussed below in the Anastomosed Fluvial Systems section.

Photomosaics and Mapping

Photomosaics were used to document lateral changes in lithofacies. Photomosaics are single or composite photographs, generally taken orthogonal to the outcrop, which are used as a base for definition of architectural elements which were sketched on overlays (Miall, 1985). In this study, photomosaics at the scale of individual outcrops were used to record lateral changes in lithofacies geometry and vertical sequence, and sedimentary structures. These features are often difficult to see on the photographs themselves but are recorded on the photomosaic to provide data on spatial relationships of architectural elements. Photographs and overlays covering up to 2 km of outcrop record lateral changes in architectural elements.

In other studies using photomosaics, photographs are generally taken from an opposing canyon wall. Due to the orientation of the two section locations which contain extensive lateral exposure (Boulder River and Strickland Creek), aerial photography was the only way to obtain photographs suitable for producing photomosaics. Air photos were taken from approximately 2000 ft. and have scale of 1:4770.

Modern Comparisons

To interpret the depositional environment of an ancient deposit, it is often useful to compare the deposits of ancient rivers with unknown morphology to the deposits of modern rivers, where morphology can be observed. For example, Smith (1983) found that by coring a modern floodplain, the thickness and width of channel deposits laid down by a river of known morphology could be determined. These data are often expressed as the ratio of width to thickness of channel sandstone bodies. In addition, the distribution of channel deposits within overbank sediments has been determined for modern flood plains (Smith and Smith, 1980; Smith and others, 1989) and can be compared with spatial distributions in the Morrison Formation.

In order to compare the dimensions of sand bodies identified as channel deposits in the Morrison Formation of southwest Montana with those of modern fluvial systems, several measurements were made. Multiple thickness measurements were taken along the outcrop where sandstone bodies were of non-uniform thickness. Where sandstone lenses pinched out completely into covered section, trenches were dug to confirm the limits of lateral extent of the sand bodies. The widths of the channel deposits were measured along outcrop; however, since the true width of a channel is measured perpendicular to flow, it follows that the width of a channel deposit must be measured perpendicular to paleoflow. This is not always possible because outcrop faces do not always form perpendicular to paleoflow. To correct for this, paleocurrent directions were determined and trigonometric corrections were made to provide width dimensions closer to the true widths of Morrison alluvial channels.

Paleocurrent Measurements

Paleocurrents were measured to calculate width to thickness ratios of channel sandstone bodies. These values were compared to data from modern alluvial systems as well as ratios published in studies of other ancient deposits. In addition, paleocurrent measurements provide knowledge of sediment transport direction and allowed for interpretations of source area location, local drainage patterns, and paleo-topography.

Paleo-flow data were taken from trough cross bedding, dinosaur bone long-axis orientation, and aligned heavy mineral stringers. These latter structures result from small scale current vortices aligned parallel to transport direction which deposit stringers of heavy mineral sand, usually in a trough or on a horizontal bed (Miall and Smith, 1989). Other measurements were taken from two dimensional exposures of trough cross-bedding. Although it can be difficult to accurately determine paleo-flow direction from two dimensional outcrops, DeCelles and others (1983) showed it was possible to obtain reasonable paleo-flow measurements (± 25 percent) by using limb truncation angles to recognize the obliquity of the outcrop cut, and correct for it qualitatively. In addition, comparisons were made with computer generated models of cross bedding (Rubin, 1987) which allowed recognition of bedding structures cut at various angles.

LITHOFACIES

Lithofacies were delineated on the basis of grain size and sedimentary structures, and to a lesser extent, induration and color. The lithofacies codes used in this section are those of Miall (1985), and in some cases have been modified. Lithofacies are divided into mudrock and sandstone lithofacies. Hydrodynamic interpretations accompany each description. Broader, depositional environment interpretations will be presented in the next section when these lithofacies are compiled into lithofacies assemblages or architectural elements.

Mudrock

Massive clay and silt (Fm)

Description: This lithofacies makes up the majority of strata in all measured sections. It is poorly indurated and often covered but was observed in slump scarps, steep slopes, and trenches. Weathered exposures are often fissile but fresh material (trenches) is massive. Thin (1 to 3 mm), laterally discontinuous, sandy silt stringers are sometimes present. Grain size ranges from silty clay to sandy silt.

Color varies from light green and red to light and dark grey. Purple horizons were found at the Strickland Creek section. At the West Boulder section the grey mudstone is slightly petroliferous. Flakes of carbon of unknown origin and small leaf fragments are common in several horizons of the green and grey mudstone. Zones 0.5 m thick with small (1 to 5 cm diameter) iron-bearing nodules occur within this lithofacies.

Interpretation: Structureless mud is deposited when fine-grained sediment settles out of suspension with little variation in settling rate and grain size (Collinson and Thompson, 1982, p. 57). The environment of deposition is one of very low energy. Red and brown zones are interpreted to have been oxidized, likely as a result of pedogenic processes (Kraus and Bown, 1988). Green and grey zones represent primary or diagenetic reducing environments. The presence of a reducing environment is indicated by preserved plant material.

Laminated clay and silt (Fl)

Description: This lithofacies is similar to Fm in grain size, color, and induration but has fine laminations that are typically 1 to 3 mm thick. These laminations are often accompanied by a change in grain size, from clay to silt or sandy silt. Uncommonly, the laminations are wavy with the waveform height ranging from 1 to 2 cm and the wavelength ranging from 5 to 10 cm.

Interpretation: This lithofacies is also the result of low energy suspension deposition. Laminations of this scale are the result of fluctuations in the supply of different sizes of suspended sediment (Collinson and Thompson, 1982, p. 56). Wavy lamination may result from soft sediment deformation or drapes on underlying ripple cross-laminated sediment.

Silty limestone (Fc)

Description: This lithofacies occurs as small lenses of light grey, silty, micritic limestone. Lenses range from 1 to 5 m in width and 5 to 20 cm in thickness. Small stringers of sparry calcite 1 to 3 mm thick are common. Upper and lower contacts are sharp and uniform.

Interpretation: These limestone lenses are interpreted to be the result of carbonate precipitation in shallow floodplain ponds or backswamps. Shallow water environments were responsible for creating similar deposits found in the Lower Cretaceous Peterson Limestone of western Wyoming and southeastern Idaho (Glass and Wilkinson, 1980). The limited lateral extent and uniform contacts preclude the possibility of these deposits being interpreted as calcretes or caliches as these pedogenic features are usually laterally extensive and nodular (Blodgett, 1988).

Coal and woody material (C)

Description: This lithofacies occurs as a zone at the transition between mud lithofacies of the Morrison Formation and sand lithofacies of the overlying Kootenai Formation. The zone varies in thickness laterally from 0.5 m to 10 cm. Coal occurs as partings up to 1 cm thick and 40 cm long, encased in medium to coarse-grained sand. The impressions of woody material are up to 1 m long and have the third dimension slightly preserved although all fragments were clearly crushed.

Interpretation: The poor quality of the preserved coaly material precluded identification (W. Tidwell, pers. comm., 1992). No in situ stumps or roots were found and fragments were all aligned parallel to one another. This, along with the fact that coal is sparse and not developed in seams indicates that trees grew upstream and were likely transported during flood events. Transport of the logs is further corroborated by their worn nature observed in the impressions. In all cases the logs had been crushed.

Sandstone

Trough cross-bedded sand (St)

Description: Fine to coarse-grained, well sorted, moderately to well indurated trough cross-bedded sand is the dominant sand lithofacies. Cross beds occasionally occur as sets 30 to 60 cm thick, 0.5 to 1.5 m wide, and always appear as cosets. Indistinct normal grading can be seen within some of the individual foresets. Cement is often calcareous.

Color is generally light yellowish brown. Dark, heavy mineral sand layers are occasionally present at the base of troughs and were exposed under overhanging exposures. The composition of this lithofacies is typically that of a sublitharenite (Folk, 1968).

Interpretation: Trough cross bedding results from the down-current migration of large sinuous crested and isolated sand dunes. As dunes migrate across and fill hollows in the substrate, concave up bedding results (Harms and Fahnstock, 1965). The dunes are created and maintained by unidirectional flow in the upper part of the lower flow regime. They form in water depths greater than twice the thickness of the individual sets (Harms and others, 1975). As such, the presence of the structure is not indicative of water depth.

Ripple cross-laminated sand (Sr)

Description: This lithofacies consists of very fine- to medium-grained, moderately well indurated sand. Ripple forms typically have an amplitude of 1 to 3 cm and wavelength of 3 to 10 cm. This lithofacies occasionally exhibits load and fluid escape structures when overlain by lithofacies St. Limonitic partings are also present. The color is yellowish brown to brown. The composition of this lithofacies ranges from sublitharenite to litharenite.

Interpretation: Ripple cross-lamination results from the down current migration of small scale bedforms (height < 3 cm, wavelength < 50 cm), produced by lower flow regime flow (Collinson and Thompson, 1982, p. 59). Ripple laminations can have various cross-sectional geometries. The ripple forms found in this lithofacies exhibit sigmoidal morphologies. Based on flume and sedimentologic studies, Jopling and Walker (1968) concluded that sigmoidal morphology represented preservation of lee side laminae with no preservation of stoss side laminae. This reflects low aggradation rates as a result of low suspended load/traction load ratios.

Scours with mudclast conglomerate (Sei)

Description: This lithofacies is a moderately well indurated, matrix-supported, mud-pebble conglomerate which always overlies an erosional scour. The clasts are predominantly 0.5 cm to 1 cm in length, but clasts up to 10 cm were found; they are grey to green, calcareous, and subangular.

The matrix is a greenish-grey to yellow, medium-grained, poorly-sorted, calcareous sand. Dinosaur bones are typically found within or closely associated with this lithofacies. Disarticulated sauropod post-cranial bones up to 1 m in length were found at the Strickland Creek site by staff from the Museum of the Rockies, along with the hind limb elements of an allosaur and several turtle scutes. The bone bed at Strickland Creek lies just below the base of a 3 m thick channel sandstone mostly contained within in a 0.2 m grey green siltstone although several poorly preserved bones were found within a 0.4 m thick unit of lithofacies Sei which lies directly above the siltstone unit. Sauropod caudal vertebrae and a cervical vertebrae of a Stegosaurid were found at the Boulder River location within this lithofacies. Impressions of woody material are also locally common.

Interpretation: This mudclast conglomerate appears to have formed in a low energy environment. The mudclasts likely formed when cohesive mudbanks collapsed into the channel as a result of bank erosion. The majority of mudclasts found at all three sections are angular and therefore could not have been transported far, or in a high energy environment. In addition, dinosaur bones found at Boulder River in lithofacies Sei showed no evidence of wear.

ARCHITECTURAL ELEMENTS

Architectural elements were defined on the basis of grain size, types of bedforms present, internal lithofacies sequence (vertical and lateral), and external geometry. Three of Miall's (1985) eight original architectural element types were recognized: channel (CH), sand bedform (SB), and overbank fines (OF). The channel element type CH has been subdivided to include three different channel classes. Fifteen individual elements were identified in the Morrison outcrops and are listed in Table 1. They can be seen best on air photos (Figures 2 and 3). Relative dimensions of element types CB and SB are graphically presented in Figure 4. Representative sketches, showing lithofacies composition and external geometry of element types CH and SB are presented in Figure 5. Element OF does not show noticeable lateral or vertical changes in the above mentioned defining parameters and was not sketched.

Channel Elements

Primary Channels (CHp)

Description: This channel element is characterized by a concave-up erosional base and the predominance of lithofacies St and Sei. Element CHp is also the largest channel element (largest cross sectional area perpendicular to paleoflow) of all the channel elements recognized (Table 1D).

Primary channel deposits have a moderately low width to thickness ratio relative to other CH elements (Table 1C). Ratios of 5.5 and 10.7 were determined for the two channel elements (1 and 11) classified as