

PALEOECOLOGY AND TAPHONOMY OF THE WILLOW TANK FORMATION
(ALBIAN), SOUTHERN NEVADA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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TABLE OF CONTENTS

1. INTRODUCTION	1
Focus of Study	1
Objectives	2
2. BACKGROUND	4
Willow Tank Formation.....	4
Early Cretaceous Biota	10
3. METHODS AND MATERIALS.....	16
Sedimentology and Stratigraphy.....	16
Stratigraphic Sections	16
Analysis.....	16
Paleontology and Taphonomy	19
Prospecting and Surface Collection	19
Screening.....	19
Excavation.....	19
Preparation and Curation	20
4. SEDIMENTOLOGY AND STRATIGRAPHY	22
Overview.....	22
Lithofacies.....	23
Massive Mudrock (Fm).....	23
Description.....	23
Interpretation.....	23
Clayshale (Fl).....	24
Description.....	24
Interpretation.....	24
Sandy Mudrock (Fsm)	24
Description.....	24
Interpretation.....	24
Massive Mudrock (Sm).....	26
Description	26
Interpretation.....	26
Trough Cross-bedded Sandstone (St)	26
Description.....	26
Interpretation.....	26
Horizontally-bedded Sandstone (Sh)	26

TABLE OF CONTENTS – CONTINUED

Description	26
Interpretation.....	27
Ripple Cross-laminated Sandstone (Sr)	27
Description	27
Interpretation.....	27
Low-angle Cross-bedded Conglomerate (Gt).....	27
Description	27
Interpretation.....	28
Volcaniclastic Sediments (Vc).....	28
Description	28
Interpretation.....	28
Lithofacies Assemblages	29
Channel Fill (CH)	29
Description	29
Interpretation.....	29
Crevasse Splay (CS)	30
Description	30
Interpretation.....	30
Overbank Fines (FF).....	30
Description	30
Interpretation.....	31
Discussion	34
5. PALEONTOLOGY	37
Systematic Paleontology	38
Vertebrates	38
Plantae.....	45
Invertebrates.....	46
Traces.....	46
Coprolites	47
Discussion	47
6. TAPHONOMY	54
Site Descriptions	54
Discussion	59
7. CONCLUSIONS.....	63
APPENDICES	66

TABLE OF CONTENTS – CONTINUED

APPENDIX A: Quarry Map of Site 3.....	67
APPENDIX B: A Review of Turtle Taphonomy	69
APPENDIX C: Measured Stratigraphic Sections and Correlated Sections.....	75
REFERENCES CITED.....	86

LIST OF TABLES

Table	Page
1. Geology of some terrestrial Lower Cretaceous formations of North America.....	5
2. Mid-Cretaceous (Albian) dinosaurs from various formations in North America	12
2 con't. Mid-Cretaceous (Cenomanian) dinosaurs from various formations in North America	13
3. Non-dinosaur fauna from various formations (Albian) in North America	14
3 con't. Non-dinosaur fauna from various Formations (Cenomanian) in North America	15
4. Lithofacies descriptions and geometries.....	25
5. Faunal list of Willow Tank Formation vertebrate taxa with localities	37
6. Taphonomic modes of fossil bearing localities in study area.....	56
7. Site 3 taphonomy	56

LIST OF FIGURES

Figure	Page
1. Relative locations of major Lower Cretaceous exposures in North America in red, the Willow Tank Formation is in yellow	2
2. Stratigraphy of Mesozoic units within the Valley of Fire, Nevada, the unconformity between the Aztec Ss and the Willow Tank Fm represents approximately 75 Ma.....	8
3. A diagrammatic stratigraphic section of relevant Mesozoic units in Valley of Fire State Park.....	9
4. Photography showing stratigraphic relationships of Aztec Ss, Willow Tank Fm and the Baseline Ss	10
5. Location of measured sections on a satellite image.....	18
6. Single storied channel sandstone bodies outlined in white.....	32
7. Lithofacies assemblage showing vertical relationship of Sh and St lithofacies, similar to the relationship of ribbon sandstones figured in Eberth and Miall (1991).....	32
8. Measured sandstone bodies clump in two statistically, non-significant groups	33
9. Mottled Fm with carbonate nodules, interpreted to be a paleosol.....	33
10. Photos of select specimens described above.....	52
11. Photos of select specimens described above.....	52
12. Stratigraphy of site 3.....	57

ABSTRACT

This study documents fossil remains from the Willow Tank Formation and places those remains into a taphonomic and sedimentological context in order to determine the paleoecology of southern Nevada during the Early Cretaceous (Albian). Recovered taxa include Lepisosteidae, *Ceratodus*, Holostean A, *Naomichelys*, Baenidae, c.f. *Adocus*, possible Trionychidae, Crocodyliformes, Thyreophora, Iguanodontia, Titanosauriformes, Tyrannosauroida, Dromaeosauridae, indet. Theropoda, and two fern morphotypes.

Sedimentology of the fossiliferous unit of the Willow Tank Formation suggests these taxa were deposited in an anastomosed fluvial system. Interpretation of an anastomosed fluvial system is based in part upon an overwhelming abundance of overbank fines, single storied channel fills, lack of lateral accretion structures, and common crevasse splay sandstones. Observed paleosols commonly contain carbonate nodules associated with mottled red-green mudrocks. The carbonate nodules are consistent with a seasonally arid environment and reddening of beds may suggest a well drained floodplain. Taphonomic modes include microsite, subaqueous bonebed, subaerial bonebed, and channel fill assemblages. Vertebrate fossils are found predominantly in overbank settings.

The fauna of the Willow Tank Formation most resembles that of the Cedar Mountain Formation. Unlike the discrete, temporal, fauna assemblages of the various members of the Cedar Mountain Formation, the Willow Tank Formation fauna contains a mix of these different stratigraphic faunas. One example is the co-occurrence of Early Cretaceous iguanodon-grade and Late Cretaceous hadrosaur-grade teeth. Another example being the presence of a tyrannosauroid tooth in Albian beds of the Willow Tank Formation, where tyrannosauroids are not found in the Cedar Mountain Formation until the Cenomanian. Therefore, Willow Tank Formation strata may shed light on biogeographic and evolutionary relationships at the Early-Late Cretaceous boundary.

INTRODUCTION

Focus of Study

In comparison to extensive vertebrate paleontological research performed in the Upper Cretaceous of North America, relatively little research has been conducted in the Lower Cretaceous. The best documented terrestrial formations of Early Cretaceous age from western North America include the Cloverly Formation of Wyoming and Montana (Ostrom, 1970) and the Cedar Mountain Formation of Utah (Kirkland *et al.*, 1997; Kirkland *et al.*, 1998; Kirkland *et al.*, 1999; Goldberg, 2000; Eberth *et al.*, 2006) (Fig. 1). The Early Cretaceous documents the marked transition from Jurassic to Late Cretaceous terrestrial ecosystems, including the radiation of the angiosperms (Wing and Sues, 1992). The effects of this floral radiation on Early Cretaceous vertebrate faunas remain unclear.

This study documents the fossil remains, as well as their taphonomic and sedimentological context, of the Willow Tank Formation, a terrestrial Lower Cretaceous unit of southern Nevada. No vertebrates have previously been described from this formation. The Newark Canyon Formation from east-central Nevada (MacNeil, 1939; David, 1941; Vandervoort, 1987; Suydam, 1988) is the only other formation within the state that holds any Cretaceous fossils, either marine or terrestrial. While close in age to the Willow Tank Formation, the Newark Canyon Formation (Barremian-Albian) (Vandervoort, 1987) was deposited in the Cordilleran hinterland (Vandervoort, 1987; Suydam, 1988; Vandervoort and Schmitt, 1990).

The fauna of the Willow Tank Formation fills a biogeographical gap in the Early Cretaceous record of western North America. There is no record of fauna having been found in as close proximity to the Sevier fold and thrust front.



Figure 1. Relative locations of major Lower Cretaceous exposures in North America in red, the Willow Tank Formation is in yellow (modified from Blakey, 2001). Geographic reconstruction represents North America during the Aptian-Albian.

Objectives

This study describes the taxonomic composition of the upper member of the Willow Tank Formation and the taphonomic and sedimentological context of the fossil remains. This study identifies recovered fossils to as low a taxonomic level as possible

given their relative states of preservation. Taphonomic analysis facilitates comparison of Willow Tank Formation biota to other contemporaneous faunas by accounting for potential differences in preservational modes between formations. Sedimentological analysis provides a framework for interpreting the taphonomy and clarification of the depositional environments of the Willow Tank Formation.

BACKGROUND

Willow Tank Formation

Exposures of the Willow Tank Formation are found in the Valley of Fire, Gale Hills, Bowl of Fire and the Virgin Mountains of southern Nevada (Bohannon, 1983). The Willow Tank Formation was originally grouped with the Baseline Sandstone within the Overton Fanlomerate (Longwell, 1921). Longwell later recognized and described the Willow Tank as a separate formation in 1949. Longwell (1949) and Bohannon (1983) recognize two distinct lithologies within the Willow Tank Formation: a basal conglomerate and an upper mudrock. The Willow Tank Formation represents synorogenic foredeep sediments of the Sevier foreland basin (Schmitt and Kohout, 1986; Schmitt and Aschoff, 2003). This foreland basin lies between the North American Cordillera and the North American craton (Currie, 2002).

Two units are defined for the Willow Tank Formation, a basal conglomerate and an upper mudrock member with interspersed sandstones (Carpenter, 1989). Reese (1989) informally recognized a third volcanoclastic member found stratigraphically between the previously defined units. However, this study follows the stratigraphy of Longwell (1949), Bohannon (1983), and Carpenter (1989). Differentiation of the basal conglomerate member from the upper mudrock member is defined by the gradational lithology change between the two. This lithologic change represents a change in accommodation and/or sediment supply.

Table 1. Geology of Some Terrestrial Lower Cretaceous Formations of North America

<u>Formation Name</u> <u>References</u>	<u>Age</u>	<u>Geographic Location</u>	<u>Tectonic Setting</u>	<u>Sedimentology</u>
Cedar Mountain Yingling, 1987; Yingling & Heller, 1992; Kirkland et al., 1997; Currie, 1998; Kirkland et al., 1999	Barremian- Cenomanian	Central Utah	Sevier retroarc foreland basin	Fluvial system, including alluvial fan deposits
Cloverly Ostrom, 1970; DeCelles & Burden, 1992	Aptian- Albian	South Central Montana, Northern Wyoming	Sevier retroarc foreland basin	Fluvial system
Newark Canyon Vandervoort, 1987; Suydam, 1988; Vandervoort & Schmitt, 1990	Barremian- Albian	East Central Nevada	Sevier retroarc hinterland	Through flowing fluvial system and lacustrine
Trinity Group Winkler et al., 1990		Texas, Oklahoma, Arkansas	Continental interior	Coastal Plain
Potomac Group Arundel Fm. Glaser, 1967; Conant, 1990; Powars, 2000; Lupia; 2004	Barremian- Aptian	Maryland, Virginia	Passive continental margin	Fluvial to swamp, fluvial-deltaic system
Willow Tank Schmitt & Kohout, 1986; Reese, 1989; Schmitt & Ashoff, 2003	Albian	Southern Nevada	Sevier retroarc foreland basin	Fluvial system

The basal member consists of two conglomeratic bodies separated by a thin carbonate paleosol (Reese, 1989). Reese (1989) concludes that the conglomerate member marks the initiation of Sevier thrusting in the region, and that fluvial sedimentation is consistent with a Donjek-type braid plain model. Many Lower Cretaceous formations of the western foreland basin are characterized by a basal conglomerate (Ostrom, 1970; Heller and Paola, 1989; Reese, 1989) (Table 1), interpreted

as a Scott or Donjek wandering braid plain (Miall, 1977). Most of these conglomerates are interpreted to represent initiation of Sevier fold and thrust tectonics in the region or, alternatively, the beginning of thermal doming to the west prior to actual thrust faulting (Schmitt and Kohout, 1986; Heller and Paola, 1989; DeCelles and Burden, 1992). These syntectonic gravels typically occur within 70 km of the advancing thrust front and represent one continuous fluvial system (Heller and Paola, 1989). Persistence within the conglomerates of limestone cobbles carried from a drainage source area 700 km to the west, as well as the carbonate paleosol indicate an arid environment (Reese, 1989).

The fossiliferous, upper mudrock member consists of mudrocks with volcaniclastic horizons and interspersed channel sandstones (Longwell, 1949; Reese, 1989). Sediments derive from exposed Paleozoic formations in the upper plate of the thrust sheets, dominated lithologically by limestone and chert (Reese, 1989). In the same work, Reese (1989) describes an informal member between the basal and upper members consisting of a thick volcaniclastic deposit.

In the study area within the Valley of Fire, the Willow Tank Formation unconformably overlies the Jurassic Aztec Sandstone and is overlain by the Upper Cretaceous Baseline Sandstone (Figs. 2, 3 & 4). The upper contact of the Willow Tank Formation is in some places sharp, and in others interbedded with the Baseline Sandstone. This suggests a conformable contact and a transition of depositional modes upsection likely related to propagation of the Sevier fold and thrust front. K/Ar dates (93.1 and 95.8 Ma) place the Baseline Sandstone in the Cenomanian (Carpenter and Carpenter, 1987). The Aztec Sandstone is interpreted to be Lower Jurassic (Blakey et al.,

1988). Ash and Read (1976) used the presence of the tree fern *Tempskya* to originally designate the Willow Tank Formation as Albian, however, more recent studies have shown that *Tempskya* has a wider stratigraphic distribution, including most of the mid-Cretaceous (Tidwell and Hebbert, 1992). Recent dates on zircons from the upper member of the Willow Tank Formation show dates of latest Albian (101 and 99 Ma) (Troyer et al., 2006). Comparison of dinosaur taxa of the Willow Tank Formation to other mid-Cretaceous formations from North America is not useful for biostratigraphy (see discussion below).

Aside from the biostratigraphic study using *Tempskya* (Ash and Read, 1976), the only other paleontological study on the Willow Tank Formation was initiated by Dr. David Varricchio of Montana State University in 1999. Varricchio recognized a number of fossiliferous localities with varying degrees of preservation. For consistency, locality numbers from this previous study are retained.

Cretaceous	Upper	Campanian	
		Santonian	
		Coniacian	
		Turonian	
		Cenomanian	
	Lower		Baseline Sandstone
		Albian	Willow Tank Formation
		Aptian	? Unconformity ?
		Barremian	
		Hauterivian	
		Valanginian	
		Berriasian	
Jurassic	Upper	Tithonian	
		Kimmeridgian	
		Oxfordian	
	Middle	Callovian	Aztec Sandstone
		Bathonian	
		Bajocian	
		Aalenian	
	Lower	Toarcian	
		Pliensbachian	

Figure 2. Stratigraphy of Mesozoic units within the Valley of Fire, Nevada, the unconformity between the Aztec Ss and the Willow Tank Fm represents approximately 70 Ma. Dates from Carpenter and Carpenter, 1987 and Marzolf, 2007.

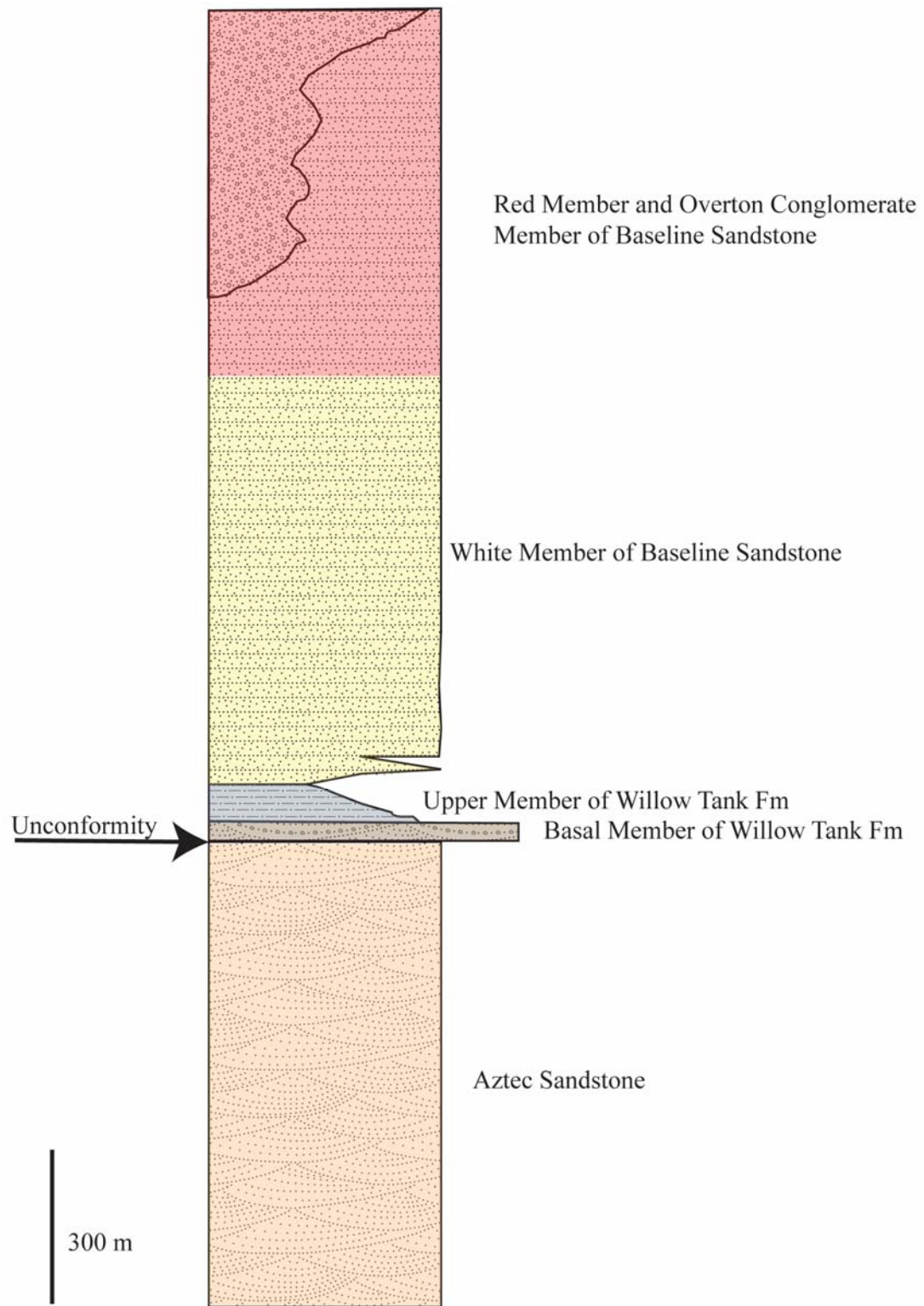


Figure 3. A diagrammatic stratigraphic section of relevant Mesozoic units in Valley of Fire State Park (after Carpenter, 1989).



Figure 4. Photograph showing stratigraphic relationships of Aztec Ss, Willow Tank Fm. and the Baseline Ss.

Early Cretaceous Biota

Early Cretaceous faunas have been described from Virginia, Maryland, Texas, Oklahoma, Montana, Wyoming, and Utah (Tables 2 and 3). Early Cretaceous biotas of North America represent a transition from Late Jurassic to Late Cretaceous fauna (Gilmore, 1922; Kirkland *et al.*, 1997; Bakker, 1998). The unique attributes of the fauna are evident even in the first studies of the time period (Gilmore, 1922).

Late Jurassic fauna of western North America are best preserved in the Morrison Formation (Dodson *et al.*, 1980; Rees *et al.*, 2004). This formation records a savanna-like alluvial plain which stretched from Montana to New Mexico (Rees *et al.*, 2004). By

the Late Cretaceous, sauropod diversity had significantly dropped and allosaurs and stegosaurs had gone extinct (Weishampel and Norman, 1989; Bakker, 1998).

Ceratopsians, hadrosaurids, ankylosaurs and tyrannosaurids predominate in the Late Cretaceous of North America (Wing and Sues., 1992; Kirkland *et al.*, 1998; Kirkland *et al.*, 1999). Kirkland *et al.* (1999) suggest that there is a faunal transition from a North American fauna more closely allied with Europe during the beginning of the Early Cretaceous to a fauna more closely allied with Asia by the end of the Early Cretaceous.

Interestingly, the Early Cretaceous fauna of North America seems homogenous across the continent (Kirkland *et al.*, 1998). The fauna found in Maryland (Kranz, 1998) is similar to those found in Montana (Ostrom, 1970), Texas (Winkler *et al.*, 1990), and Utah (Kirkland *et al.*, 1998) (Table 2 and 3). Consequently, Kirkland *et al.* (1998) propose that the faunal composition of the various members of the Cedar Mountain Formation can be used for biostratigraphy.

In addition to the fauna record, there is also a diverse floristic record, palynological and macrofloral, from formations of the Lower Cretaceous. This floral record documents the first appearance of angiosperms during the middle part of the Early Cretaceous (Barremian). By the late Early Cretaceous (Aptian) angiosperms had spread all the way to the poles (Feild and Arens, 2005). This significant evolutionary event undoubtedly had a large impact on the terrestrial ecosystems of the Early Cretaceous.

Table 2. Mid-Cretaceous (Albian) Dinosaurs from various formations in North America

<u>Cedar Mountain Fm.</u> Ruby Ranch & Yellow Cat Mbrs. (Kirkland et al., 1997; Kirkland et al., 1998; Kirkland et al., 1999)	<u>Cloverly Fm.</u> (Ostrom, 1970; Sues, 1980)	<u>Arundel Fm.</u> (Kranz, 1998)	<u>Trinity Grp.</u> (Nydam et al., 1997)
Theropoda Coelurosauria <i>Nedcolbertia</i> Dromaeosauridae <i>Utahraptor</i> <i>Deinonychus</i> Troodontidae Allosauridae <i>Acrocanthosaurus</i> Indeterminate family <i>Richardoestesia</i>	Theropoda Coelurosauria <i>Microvenator</i> Dromaeosauridae <i>Deinonychus</i> Ornithomimidae <i>Ornithomimus</i>	Theropoda	Theropoda Dromaeosauridae <i>Deinonychus</i> Allosauridae <i>Acrocanthosaurus</i>
Sauropoda Brachiosauridae <i>Pleurocoelus</i> Camarasauridae Titanosauridae	Sauropoda Titanosauridae	Sauropoda	Sauropoda Brachiosauridae <i>Pleurocoelus</i>
Ornithopoda Iguanodontia <i>Iguanodon</i> <i>Tenontosaurus</i>	Ornithopoda Iguanodontia <i>Tenontosaurus</i> Hysilophodontidae <i>Zephyrosaurus</i>	Ornithopoda Iguanodontia <i>Tenontosaurus</i>	Ornithopoda Iguanodontia <i>Tenontosaurus</i>
Thyreophora Ankylosauridae <i>Gastonia</i> <i>Shamosaurus</i> Nodosauridae <i>Sauropelta</i>	Thyreophora Nodosauridae <i>Sauropelta</i>	Thyreophora Nodosauridae	

Table 2 con't. Mid-Cretaceous (Cenomanian) Dinosaurs from various formations in North America.

<u>Wayan Fm. (Idaho)</u> (Krumenacker et al., 2007)	<u>Cedar Mountain Fm.</u> Mussentuchit Mbr. (Cifelli et al., 1999)
Theropoda	Theropoda
Dromaeosauridae	Dromaeosauridae
Indet. Family	Troodontidae
	Tyrannosauridae
	<i>Alectrosaurus sp.</i>
	Indet. Family
	<i>Richardoestesia sp.</i>
	Sauropoda
	Brachiosauridae
	cf. <i>Astrodon sp.</i>
Ornithopoda	Ornithopoda
Indet. Family	Hypsilophodontidae
Hypsilophodontidae	<i>Zephyrosaurus sp</i>
	Indet. Genera
Iguanodontia	Hadrosauridae
Tenontosaurus sp.	
	Pachycephalosauridae
	Neoceratopsia
Thyreophora	
Ankylosauridae	

Table 3. Non-dinosaur Fauna from various formations (Albian) in North America.

<u>Cedar Mountain Fm.</u> Ruby Ranch and Yellow Cat Mbrs. (Kirkland et al., 1997; Kirkland et al., 1998; Kirkland et al, 1999)	<u>Cloverly Fm.</u> (Ostrom, 1970; Sues, 1980)	<u>Arundel Fm.</u> (Kranz, 1998)	<u>Trinity Grp.</u> (Nydham et al., 1997)
Crocodyloformes	Crocodyloformes Mesosuchia	Pterosauria Crocodyloformes	Crocodyloformes <i>Bernissartia sp.</i> Atoposauridae Goniopholidae Pholidosauridae
Chelonia Cryptodira <i>Glyptops sp.</i>	Chelonia Cryptodira <i>Glyptops plicatulus</i> <i>Naomichelys sp.</i>	Chelonia Cryptodira <i>Glyptops caelatus</i> <i>Naomichelys speciosa</i> Amphibia Frog	Chelonia Cryptodira Glyptopsidae <i>Naomichelys</i> Amphibia Anura <i>Albanerpeton</i>
Fish Chondrichthyes <i>Hybodus sp.</i> Osteichthyes <i>Ceratodus sp.</i> <i>Semionotus sp.</i> <i>Amia sp.</i>	Fish Osteichthyes <i>Ceratodus frazieri</i> Amioid	Fish Chondrichthyes <i>Hybodus sp.</i> Osteichthyes <i>Ceratodus sp.</i>	Fish Chondrichthyes <i>Hybodus sp.</i> <i>Lissodus</i> <i>anitae</i> Osteichthyes <i>Gyronechus</i> Amiidae Semionotidae Lepisosteidae

Table 3 con't. Non-dinosaur fauna from various formations (Cenomanian) in North America

<u>Wayan Fm.</u> (Krumenacker et al, 2007)	<u>Cedar Mountain Fm.</u> Mussentuchit Mbr. (Cifelli et al., 1999)
	Avialae
	Hesperornithiformes
	Mammalia
	Triconodontidae
	Multituberculata
	Symmetrodonta
	Tribotheria
	<i>Kokopellia juddi</i>
	Marsupialia
Crocodyliformes	Crocodyliformes
	Bernissartiidae
	Goniopholididae
	Atoposauridae
	Teleosauridae
	Pholidosauridae
Chelonia	Chelonia
	Cryptodira
	<i>Glyptops sp.</i>
	<i>Naomichelys sp.</i>
	Baenidae
	Squamata
	Teiidae
	?Scincidae
	?Paramacellodidae
	?Necrosauridae
	?Helodermatidae
	Serpentes
	<i>Coniophis sp.</i>
	Amphibia
	Caudata
	Anura
	<i>Albanerpeton arthridion</i>
Fish	Fish
	Chondrichthyes
	<i>Hybodus sp.</i>
	<i>Polyacrodus parvidens</i>
	<i>Lissodus sp.</i>
	Orectolobidae
	Rajiformes
	Myliobatiformes
Osteichthyes	Osteichthyes
Semionotidae	Neopterygii
	Lepisosteidae
	Pycnodontidae
	Amiiformes
	<i>Ceratodus sp.</i>

METHODS AND MATERIALS

Study of the Willow Tank Formation encompasses three analyses, sedimentology/stratigraphy, paleontology, and taphonomy. The methods are treated in two groups: 1) sedimentology and stratigraphy, 2) paleontology and taphonomy. This study was restricted to exposures of the Willow Tank Formation found within the boundaries of the Valley of Fire State Park, Clark County, Nevada.

Sedimentology and Stratigraphy

Stratigraphic Sections

Stratigraphic sections were measured using a Jacob's staff and Brunton compass. Beds were described based upon grain size, bedding, sedimentary structures, lithology and, occasionally, color. Sections were measured perpendicular to structural strike along the exposures of the study area. They were also measured in proximity to fossil bearing locations which had good exposure (Fig. 5).

Analysis

Lithofacies were identified and placed into a stratigraphic framework using description and terminology after Miall (1977, 1996). The relationships of the lithofacies were then used in a facies analysis. Lithofacies were determined using lithology, sedimentary structures, grain size, and color. Reoccurring lithofacies assemblages were identified and used to determine depositional environments based upon models from previous studies (after Miall, 1996). Sections are correlated using volcanoclastic units.

These volcanic units have diagnostic features which make them ideal for correlation, for example only one volcanic unit contains charcoal inclusions. Others can be traced across exposures. Interpretations are based on comparisons to other formations and models of fluvial systems (Allen, 1977; Hallam, 1981; Rust, 1981; Makaske, 2001).

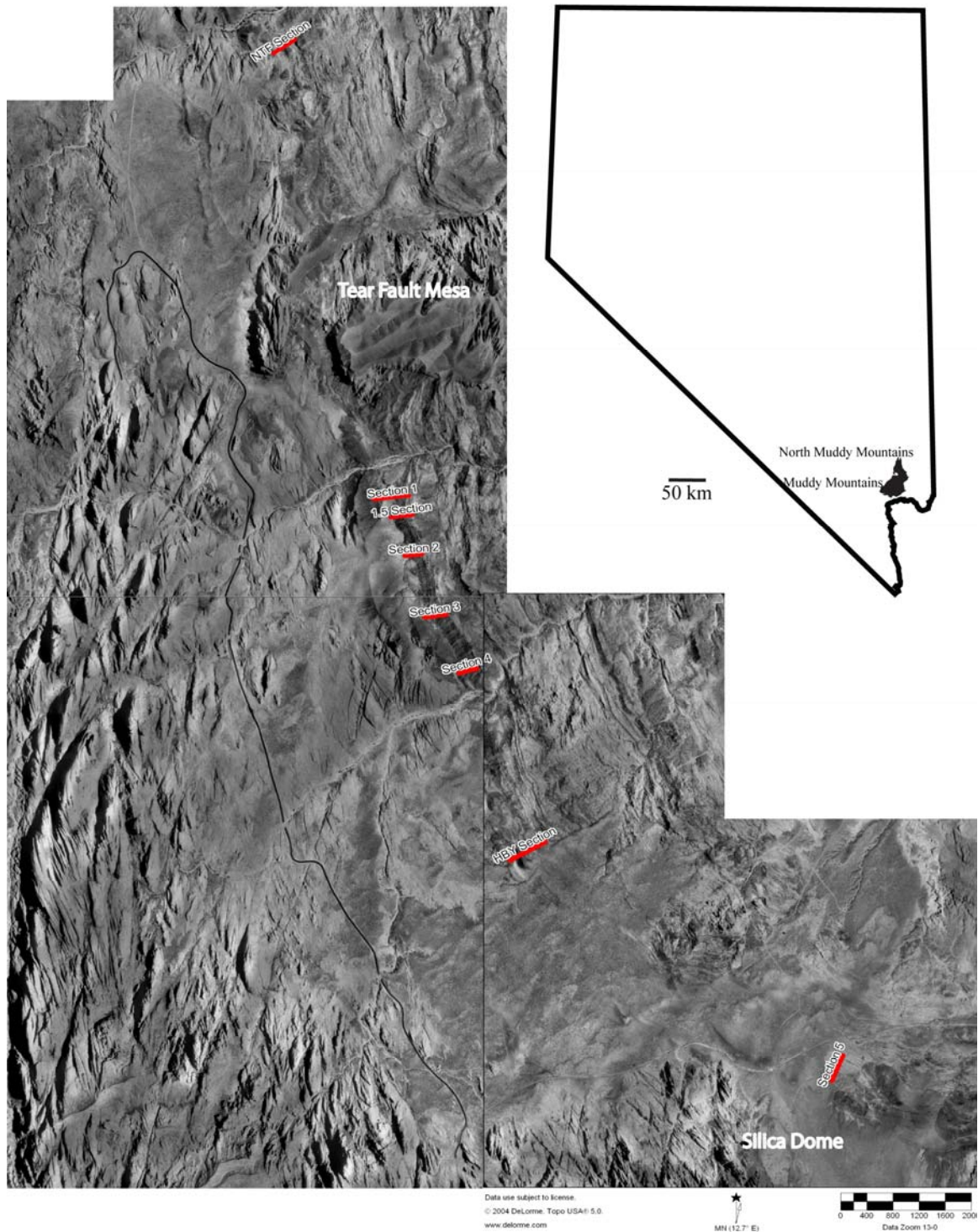


Figure 5. Location of measured sections on a satellite image. Red lines denote sections. Section numbers correspond to site numbers, HBV corresponds to site 8, NTF corresponds to site 10. Sites 6, 7, 9, 11 and 12 are not shown on this figure.

Paleontology and Taphonomy

Prospecting and Surface Collection

Fossil localities were discovered by prospecting exposures of the Willow Tank Formation within the Valley of Fire. All isolated and significant material was mapped on a 1:24,000 topographic map, GPS location was recorded and the specimen was then collected. If material appeared to be abundant or *in situ*, it was left for more thorough collection methods.

Screening

Microsites and overburden, from quarries, were screened using both dry and wet screening techniques. The majority was wet screened, as it yielded a more successful recovery of specimens, compared to dry screening.

Dry screening was performed in a boxed screen with a 1/16" mesh. The box is shaken to separate sediment from potential fossil material. Wet and dry screening is similar processes, with the exception that wet screening is submerged or filtered by water. Wet screening was also the preferred method because it is gentler on specimens, resulting in less breakage.

Excavation

Careful excavation techniques were used on significant *in situ* material. A grid was staked parallel to bedding over the area to be excavated, and measured in 1 m² quadrants. Overburden was removed and *in situ* remains were mapped on grid paper. Polyvinyl acetate was applied to exposed specimens for stabilization. After specimens

were mapped, they were given a field number and removed in either a plastic bag or plaster jacket if material was intact.

All of the recovered specimens were later analyzed to assess taphonomic data not collected in the field. This includes documentation of weathering stage using Behrensmeyer (1978) and abrasion stage using Shipman (1981) for non-turtle shell elements and Brand et al. (2000) for turtle shell elements. The abrasion scale for turtle shell established by Brand et al. (2000) compares the amount of rounding and erosion of the periphery of turtle shell elements. Based upon the amount of rounding, a score of 0-4 is assigned with a zero being an unrounded element and a 4 missing the entire articular edge of the element, along with rounding of the body of the element (Brand et al., 2000). Quarry maps (Appendix A) were used to look for patterns in the deposition of vertebrate remains.

Preparation and Curation

Materials were brought back to the Department of Earth Sciences, Montana State University-Bozeman for preparation and initial curation. Specimens were removed from the field packaging, while the field number was recorded for consistency. Most of the specimens were recovered in small fragments, requiring careful reconstruction. The most common glue used in preparation was a cyanoacrylate; some specimens were glued using white glue. Once specimens were reassembled, excess matrix was removed. Matrix and calcite rinds were removed using a dental pick, and the exposed surfaces were cleaned using a tooth brush and water. After the surface was clean, polyvinyl acetate was applied in order to further stabilize the specimen. Prepared specimens were placed into an acid

free curation box with a label indicating the specimen's field number.

As part of the curation process, recovered elements were individually identified to as low a taxonomic level as possible, (i.e. Cryptodire, Baenidae costal). Upon completion of this Masters thesis research project, all materials will be returned to the State of Nevada to be repositied and curated at the Nevada State Museum and Historical Society-Las Vegas.

SEDIMENTOLOGY AND STRATIGRAPHY

Overview

In the study area, the Willow Tank Formation strikes at approximately 150° and dips at approximately 35° to the east. Further, in the study area the upper member is approximately 60 meters in thickness. Eight stratigraphic sections through the upper member were measured at localities along strike of the formation (Fig. 5), seven of these correspond to fossil localities with the final one being intermediate between two locations. The one section measured between fossil locations was named section 1.5, referring to the position between sites 1 and 2. Paleoflow of the basal member is from the west (Reese, 1989); thus the exposures likely represent a transect perpendicular to current direction and provide a depositional cross-section of the formation. The transition from basal conglomerate to the upper member is a sharp contact.

Stratigraphic sections (Appendix C) are correlated using prominent lithologic beds, typically volcanics. The lateral continuity and distinct content of these beds make correlation relatively unambiguous. Section height varies based upon the quality of the exposures. Reactivated sand derived from the Aztec Sandstone covers the base of the formation in some areas. Additionally, talus from the Baseline Sandstone covers the upper contact of the Willow Tank Formation in areas. Sections begin just above the covered interval in areas where the base is obscured.

Measured sections consist of approximately 15 % volcanic and 85% siliciclastic lithofacies by measured thickness. Mudrock lithofacies are more common than all of the

other coarser lithofacies combined. The relative percentages of measured siliciclastic lithofacies are ~75% mudrock, ~24% sandstone, and less than 1% conglomerate.

Lithofacies

The lithofacies of the upper member of the Willow Tank Formation consists predominately of mudrocks with occasional sandstones and rare conglomerates. The observed lithofacies include massive (Fm), laminated (Fl), and sandy (Fsm) mudrocks; massive (Sm), trough cross-bedded (St), horizontally bedded (Sh), and ripple cross-laminated (Sr) sandstones; and low-angle cross-bedded conglomerates (Gl) (Table 4).

Massive Mudrocks (Fm)

Description: Fm lithofacies contain no sedimentary structures. These lithofacies range from a few centimeters to meters thick. Fm lithofacies are diverse in color, and commonly occur mottled red and green to just red or green. Another variety of Fm is brown in color and contains abundant organic material. Red and green Fm lithofacies sometimes contain carbonate nodules. Green and Red Fm beds are far more common (88%) than brown, organic Fm (12 %). This lithofacies is found interbedded with Fsm and rarely Fl. Red and Green Fm beds decrease in frequency, stratigraphically, at the top of the formation.

Interpretation: Hydrodynamically, massive mudrocks form from the settling of fine-grained clastics from suspended load of rivers in the absence of shear stress or excessive turbulence (Miall, 1977; Ghibaudo, 1992).

Clayshale (Fl)

Description: Laminated clayshale lithofacies, are horizontally laminated and range in thickness from a few centimeters to ten centimeters of fissile clay. These lithofacies are green in color. Fl lithofacies are non-fossiliferous. Fl is found interbedded with Fsm and Fm lithofacies.

Interpretation: Fl lithofacies form as a result of settling of clay sized clastics in the absence of shear stress or turbulence (Miall, 1977; Boggs, 2003).

Sandy Mudrock (Fsm)

Description: Fsm lithofacies are massive mudrocks which contain a large proportion of very-fine sand. Fsm lithofacies range from tens of centimeters thick to meters thick. This lithofacies can be mottled red and green, red, or green in color. Fsm is found interbedded with Fm and rarely with Fl.

Interpretation: Sandy massive mudrocks form from the settling of fine-grained clastics from suspended load in the absence of shear stress or excessive turbulence (Miall, 1977).

Table 4. Lithofacies descriptions and geometries.

<u>Lithofacies</u>	<u>Description</u>	<u>Geometry</u>
Fm	Massive mudrock beds, come in reds, greens, mottled red-green and brown. The red, green, and mottled beds often have carbonate nodules or less commonly, mud clasts. Less common brown beds contain a high organic component, carbonized plant material and petrochemical smell.	Occur commonly as poorly indurated thick (>1m) intervals, and less common well indurated intervals related to tephras. Beds are tabular in geometry, most types are laterally traceable for 100's of meters.
Fl	Laminated clay facies. These beds have no inclusions or fossils and exhibit "popcorn" texture when wet.	Occur as thin beds, often .3-.5m with the thickest being 1m. Laterally continuous over tens of meters.
Fsm	Mudrocks with a fine to very fine sand component. These come in reds, greens, mottled red-green, tan, and brown in color. Many of the beds with this lithofacies contain carbonate nodules.	Occur most commonly as thick (>1m) beds which are laterally continuous for 100's of meters. These beds typically have a tabular geometry.
Sm	Massive sandstones. The majority are poorly indurated with some cryptic sedimentary structures.	Sm units can be thick (>2m) units related to lenticular sandstone bodies or thin (<2m) related to sandstone bodies with sheet-like geometry and are laterally traceable for 100s of meters.
St	Trough cross-bedded sand bodies.	Sets occur in channel fills which can be thick (>1m) and are not laterally continuous and are lenticular in geometry.
Sh	Horizontally bedded sand bodies. These occur as homogenous sets and sometimes along with St.	Sets can be thick (>1m) and lenticular. Sets can also occur in sheet sandstones which are laterally traceable for over 10s of meters.
Sr	Cross bedded sand bodies. These occur in homogenous sets or with other sand lithofacies and generally are well indurated.	Sets can be thick (>1m) and are associated with lenticular sandstone bodies.
Gl	Low-angle cross-bedded conglomerate.	Lens shaped, can be over a meter in thickness with faint cross-bedding.
Vc	Volcanic grains which commonly exhibit signs of flow. Some beds are massive. Biotite grains are common in some beds. Grains of pumice and biotite are coarse sand-sized.	Beds range from a few centimeters up to 10 meters. This lithofacies is laterally continuous for kilometers.

Massive Sandstone (Sm)

Description: Massive sandstone lithofacies are composed of fine to medium sand and has no discernable sedimentary structures. This lithofacies ranges in thickness from a few centimeters to over ten meters. The most common association of Sm is with Sh, the beds of which often are interbedded with Fm or Fsm lithofacies.

Interpretation: Massive sandstones form from deposition of sediment gravity flows or from the secondary loss of sedimentary structures as a result of dewatering or bioturbation (Lowe, 1982; Smith, 1986).

Trough Cross-bedded Sandstone (St)

Description: Trough cross-bedded sandstones are composed of fine to coarse sand and have a concave up pattern in cross-section. This lithofacies ranges from one to five meters in thickness. This facies is commonly interstratified with lithofacies Sh.

Interpretation: The trough cross stratification is the result of the migration of 2-D and 3-D sand dunes downstream (Miall, 1977). Hydrodynamically, trough cross bedded sandstone lithofacies can occur from current velocities ranging from 0.3 m/s to ~1 m/s and in flow depths of 8 cm to >10 m (figured in Miall, 1996 p. 113).

Horizontally-bedded Sandstone (Sh)

Description: Horizontally-bedded sandstone lithofacies are composed of fine to coarse sand and are horizontally laminated. This lithofacies ranges in thickness from a

few centimeters to two meters. This lithofacies has two associations: 1) with St and Sr in beds less than 50 m laterally and which are commonly greater than 2 m thick; 2) with Fm and Sm in beds which are laterally traceable for up to kilometers and which are less than 2 m thick.

Interpretation: Horizontally-bedded sands are deposited as the result of upper-flow regime plane beds in water velocities of ~ 1 m/s at water depths of 0.25-0.5 m (Allen, 1984). Horizontally-bedded sands can also occur in situations with slower velocity in shallower water under lower flow regime plane beds (McBride et al., 1975).

Ripple Cross-laminated Sandstone (Sr)

Description: Sr refers to cross-laminated fine to medium sands in sets a few centimeters thick. Beds of Sr range from a few centimeters to a decimeter. Sr is found in association with beds of Sh and St.

Interpretation: The thickness of the sets is indicative of ripple migration down stream (Miall, 1977; Reineck and Singh, 1980). Ripple migration occurs at velocities of less than 1 m/s (Miall, 1996 p. 115).

Low-angle cross-bedded Conglomerate (Gl)

Description: Low-angle cross-bedded conglomerate is composed of cross-bedded pebbles to cobbles. This lithofacies is a few meters thick. Only one occurrence of this

lithofacies was measured. This lithofacies was found in association with Sh and was laterally traceable for a few tens of meters.

Interpretation: Cross-bedded conglomerates can occur under a range of hydraulic conditions (Miall, 1996 p. 108). Low-angle cross-bedding can form from the downstream migration of longitudinal gravel bars as figured in Lunt and Bridge (2007).

Volcaniclastic Sediments (Vc)

Description: Vc units are composed of volcaniclastic sediments. These sediments are white colored and range from clay to coarse sand in size. Vc units occasionally contain cross-bedding, planar bedding, and massive bedding. Cross-bedded units contain coarse sand sized pumice fragments. Some massive beds include millimeter sized biotite minerals. Bedded volcanic sediments range from a meter to five meters in thickness.

Interpretation: Sedimentary structures found in some Vc beds suggest that volcaniclastic sediments represent reworked material on the floodplain. Other Vc beds are reminiscent of primary air fall tuff.

Lithofacies Assemblages

Channel Fill (CH)

Description: The first lithofacies assemblage is a vertical and horizontal relationship of Gl, Sh, St, Sr, and occasionally Sm in the same bed. Gl is found only in one section but is associated with the above mentioned lithofacies. Laterally adjacent to these beds are commonly the reddened and mottled red-green varieties of Fm and Fsm which often contain carbonate nodules. Vertically the Gl, Sh, St, Sr, Sm bed tops is either a sharp contact with Fm or Fsm or is interbedded at cm scale. The base of these beds is typically a sharp contact with finer lithofacies. The Gl, Sh, St, Sr, Sm beds are lenticular in geometry and are single storied (Fig. 6). The basal contact of these beds are concave up and taper laterally in both directions away from the center of the bed. These beds range from a few meters to over ten meters thick.

Interpretation: This assemblage is interpreted to represent channel fill deposits. The single storied pattern of the sandstone lithofacies and their sharp, lateral contacts, with fine lithofacies are characteristic of anastomosed fluvial channel fills (Eberth and Miall, 1991; Nadon, 1994; Makaske, 2001). The relationships of the lithofacies of these channel fill deposits can be found in figure 7.

Crevasse Splay (CS)

Description: The second sandstone lithofacies assemblage consists of Sm and Sh lithofacies found in the same bed. Vertically these lithofacies are bounded, top and bottom, by Fm and Fsm lithofacies. Vertical contacts are sharp and parallel to underlying units. The geometry of this lithofacies assemblage is tabular, and these can be traced for hundreds of meters. This lithofacies assemblage ranges from tens of centimeters to two meters in thickness.

Interpretation: This second lithofacies assemblage represents crevasse splay deposits. The tabular geometry, lateral extent, and thickness of these assemblages are consistent with other records of crevasse splay deposits (Allen, 1970; Nadon, 1994). Further, thin sandstone bodies with a high amount of Sh lithofacies are indicative of crevasse splay deposits (Brierly, 1996). The channel fills and crevasse splay assemblages possess distinctive geometries and can be differentiated based upon their width: thickness ratios (Fig. 8). Sandstones with a lower width: thickness ratio are consistent with channel fill sandstones, those with a higher ratio are consistent with crevasse splay sandstones.

Overbank Fines (FF)

Description: There are two mudrock lithofacies assemblages, the first is the red, green, and mottled red-green Fm and Fsm lithofacies along with occasional Vc and rare Fl lithofacies. These beds are tabular in geometry and many contain carbonate nodules (Fig. 9). These assemblages are laterally traceable for hundreds of meters and can be

from a few centimeters to tens of meters thick. These assemblages have sharp contacts with sandstone lithofacies. The second mudrock lithofacies assemblage is much rarer than the first assemblage. The second assemblage consists of Fm lithofacies which have a dark brown color and a faint petrochemical scent; these units also have sharp contacts with Fm, Fsm, and Vc facies.

Interpretation: Both mudrock lithofacies assemblages represent flood plain deposits. The tabular geometry and reddening/mottling of beds is consistent with the deposits of a well drained flood plain (Willis and Behrensmeier, 1994). Carbonate nodules represent caliche nodules and root casts (Fig. 9), features common in seasonally arid flood plain soils (Mack et al., 1993). Petrochemical scent, dark color, and plant debris suggest that this assemblage is organic rich. The fine grain size coupled with the accumulation of organics implies subaqueous deposition (Rogers, 1993).



Figure 6. Single storied channel sandstone bodies outlined in white. View is oblique to strike, toward the south.

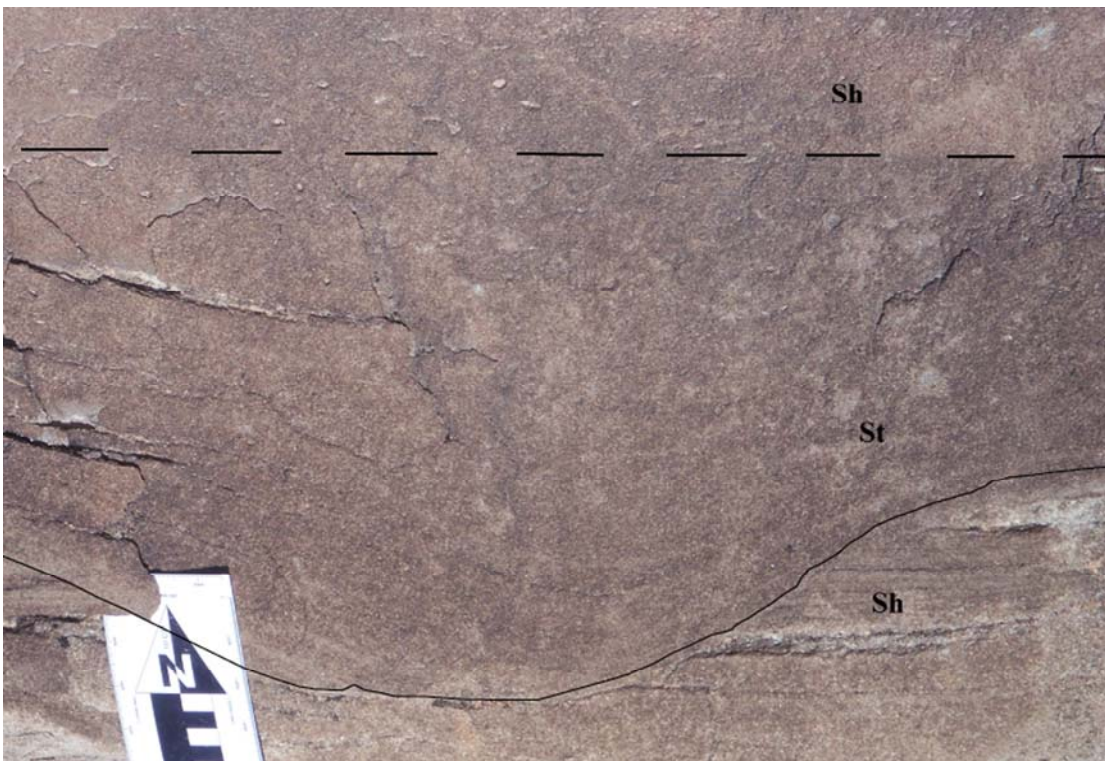


Figure 7. Lithofacies assemblage showing vertical relationship of Sh and St lithofacies, similar to the relationship of ribbon sandstones figured in Eberth and Miall (1991).

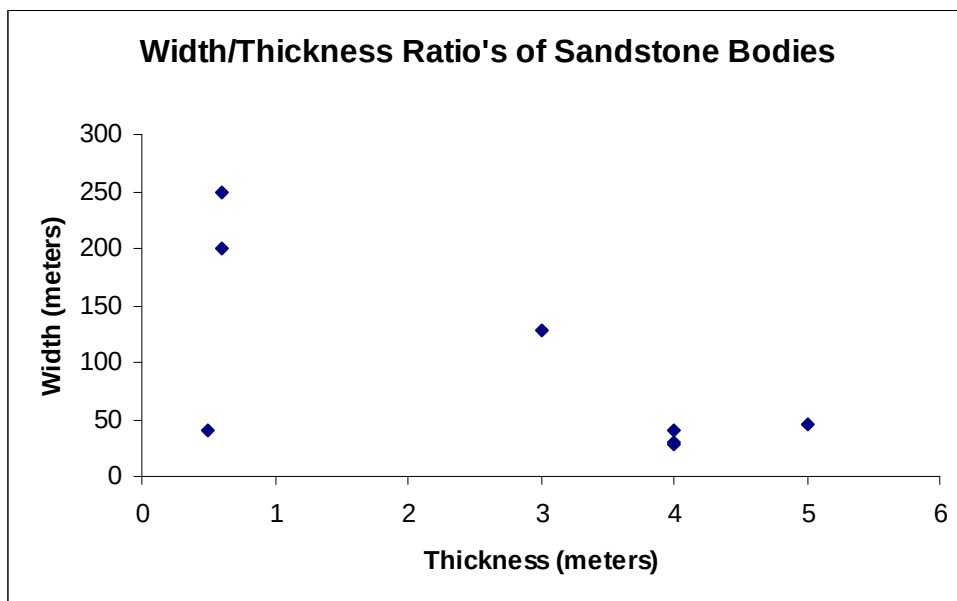


Figure 8. Measured sandstone bodies clump in two statistically, non-significant groups. The group to the lower right is all interpreted to be channel fill sandstones, the group to the left is all interpreted to be crevasse splay sandstones.

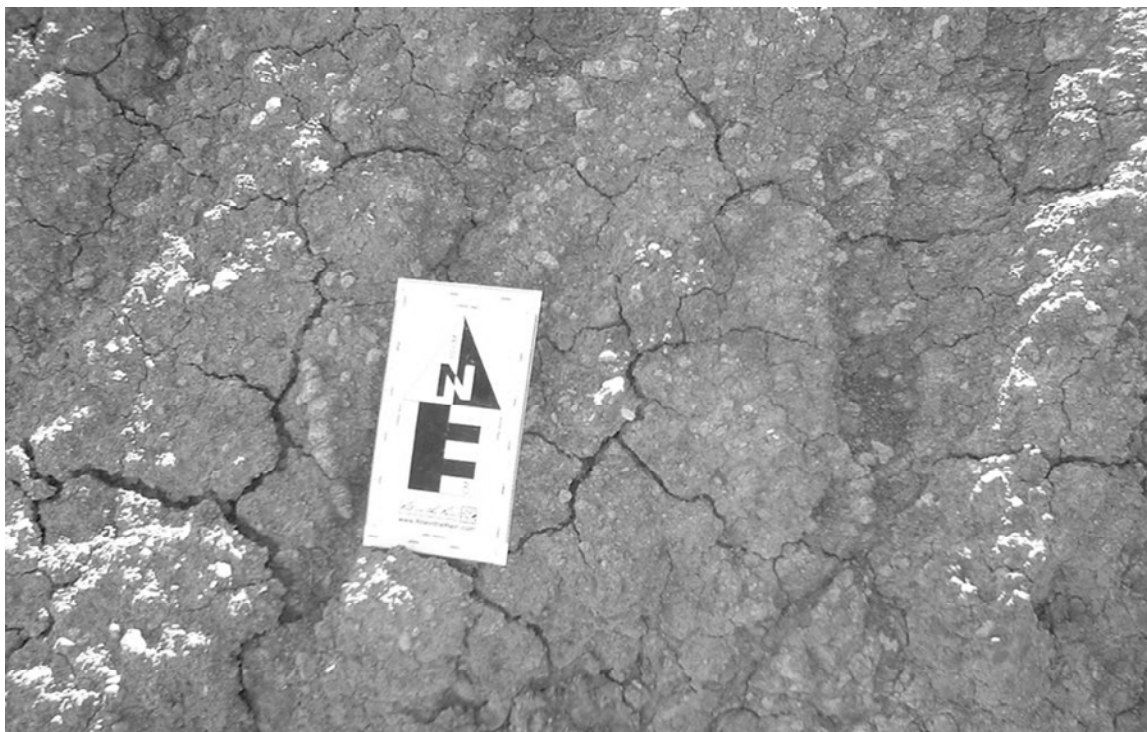


Figure 9. Mottled Fm with carbonate nodules, interpreted to be a paleosol. Note rootcast to left of scale bar.

Discussion

A comparison of the stratigraphy of the upper member to models of various fluvial systems (Rust, 1981; Nadon, 1994; Miall, 1996; Makaske, 2001) supports the interpretation of this member as being deposited in an anastomosing fluvial system. Deposits of a meandering system differ from those of anastomosing systems in containing lateral accretion structures and fining upward successions (Allen, 1977; Hallam, 1981). Braided rivers often carry a bedload of gravel due to the high energy of the system (Allen, 1977); overbank fines and floodplain deposits are not common in many braided river systems (Hallam, 1981).

Makaske (2001) established six criteria for identifying the deposits of an anastomosed fluvial system. These six criteria include: a large proportion of overbank deposits, laterally extensive fine-grained avulsion deposits, ribbon shaped channel sandstone bodies, channel deposits predominately consist of sandstone with abruptly overlying mudrock, crevasse splay deposits common, and lacustrine and coal deposits common except in arid environments (Makaske, 2001). Makaske (2001) notes that none of his criteria are unique to anastomosed fluvial systems; it is the combination and the lateral extent of these criteria which makes diagnosis of the deposits of an anastomosed fluvial system possible. Previous studies (Nadon, 1994; Makaske, 2001; Wang et al., 2005) suggest that anastomosing fluvial systems would most likely be preserved in regions with a high rate of subsidence and sedimentation. This is similar to the Sevier foreland during the Early Cretaceous (Currie, 2002). Further, regions with thick silt and clay alluvium tend to facilitate anastomosis (Makaske, 2001; Wang et al., 2005).

The upper member of the Willow Tank Formation exhibits attributes consistent with criteria of an anastomosed system. The Willow Tank Formation consists predominantly of mudrock lithofacies interpreted as overbank deposits. Laterally extensive avulsion deposits are recognized by the presence of paleosols between weakly weathered mudrock horizons in association with single-storied sandstone bodies (Slingerland and Smith, 2004). Willow Tank Formation channel fills cannot be determined as ribbon shaped due to the two dimensional exposure but are composed mostly of sandstones. These channel sandstones are abruptly truncated by mudrock lithofacies. Crevasse splays are common in Willow Tank Formation deposits. There is evidence for some ponding (dark brown, organic rich Fm lithofacies) in Willow Tank Formation exposures; although most overbank deposits suggest a drier climate. The position of the Willow Tank Formation in the foredeep of the Sevier foreland basin (Schmitt and Kohout, 1986; Schmitt and Aschoff, 2003) is consistent with a rapidly subsiding basin. All of these criteria are consistent with an anastomosed fluvial style of deposition. Exposures of the Willow Tank Formation in regions outside of the study area may represent different fluvial systems without contradicting this interpretation for the Valley of Fire. It is possible for different fluvial modes to operate on different reaches of the same river (Nanson et al., 1986).

The mudrocks of the upper member represent deposits on a floodplain. These overbank fines predominantly show signs of pedogenesis in a well drained, seasonally arid environment. The paleosol horizons present in the formation are largely red or mottled red-green and often contain abundant caliche nodules; this is consistent with a

Calcisol (Mack et al., 1993). These Calcisols are evidence for deposition in a seasonally arid to semi-arid environment (Mack et al., 1993; Retallack, 2001). Reddening is consistent with a well drained, floodplain (Behrensmeyer et al., 1992). This evidence is consistent with previous paleoenvironmental interpretations by Reese (1989), who interpreted persistent limestone clasts and a calcareous paleosol in the lower member as indicative of deposition in a semi-arid region.

The frequency and thickness of volcanoclastic lithofacies in the upper member of the Willow Tank Formation suggests that there was a volcanic source area in the vicinity of the basin in which these deposits were interred. Overall the Willow Tank Formation deposits represent deposition in a seasonally semi-arid environment with relatively frequent volcanoclastic input. Further, the style of deposition in this region records a sharp change in depositional style from a pebble-cobble, dominated braided system to a mud-sand dominated anastomosing system.

PALEONTOLOGY

Fossil material was collected from 10 localities within the Willow Tank Formation in the Valley of Fire State Park. Taxa recovered from these sites include numerous vertebrates (Table 5), one invertebrate, one ichnotaxon, and two plant taxa. Elements comprising the dinosaur material are primarily teeth. Site 11 consists of potentially associated ornithopod elements and Site 10 has produced a theropod femur and tibia (Table 6).

Table 5. Faunal list of Willow Tank Formation vertebrate taxa with localities. Localities with no identifiable vertebrate remains were excluded.

<u>Taxa</u>	<u>Site</u>						
	2	3	4	5	8	10	11
Theropoda							
Dromaeosauridae						X	
Tyrannosauroidae				X			
Indeterminate Family		X		X			
Sauropoda							
Titanosauriformes				X			
Ornithopoda							
Iguanodontia		X		X			X
Thyreophora			X	X			
Crocodylomorpha	X	X	X	X		X	
Chelonia							
Cryptodira							
Baenid		X					
<i>Naomichelys</i> sp.		X			X	X	
c.f. <i>Adocus</i>		X					
?Trionychidae?				X			
Fish							
Osteichthys							
<i>Ceratodus</i> sp.		X					
Lepisosteidae		X	X	X			
Holostean A		X	X	X			

Systematic PaleontologyVertebrata

OSTEICHTHYES Huxley, 1880
SARCOPTERYGII Romer, 1955
DIPNOI Muller, 1845
CERATODONTIDAE Gill, 1872
CERATODUS Agassiz, 1837

Description: Two tooth plates were recovered. The morphology of these tooth plates compares closely to published specimens of the genus *Ceratodus* (Ostrom, 1970; Kemp, 2001). The tooth plates possess four ridges which have a radiating pattern extending across the short axis of the plate. The ridges are separated by notches which have a u-shaped base. Tooth plate specimen 1 (VOF-2005-03-003) is more robust and nearly complete with one end not preserved along the long axis. The total length of the long axis is 15 mm, minus the missing end; the width of the tooth plate excluding the attached bone underneath is 13 mm. The ridges running the long axis of the specimen are 1-2 mm apart and become closer and less pronounced as they culminate at the unpreserved portion of the specimen. The less robust tooth plate (VOF-2005-03-2A-001) is complete (Fig. 10A). The length of the long axis length is 18 mm with the maximum width 11 mm, as measured from the widest point. The tooth tapers to a point making a triangular pattern in occlusal view. The plate contains four ridges trending toward the same point, one of the corners on the widest side of the tooth. The ridges measure up to 2 mm in height with the crests of the ridges up to 3 mm apart, culminating and becoming less pronounced upon merging at the corner of the tooth.

ACTINOPTERYGII Cope, 1887
 LEPISOSTIFORMES Berg, 1940
 LEPISOSTEIDAE Cuvier, 1825

Description: The only remains of gar fish having been found in the Willow Tank

Formation consist of ganoid scales. The scales measure from 2-3 mm along the short axis and up to 4 mm along the long axis. They have an enamel covering on only one side and tend to be rectangular to rhombohedral in shape.

HOLOSTEAN A Brinkman, 1990

Description: Holostean A is a grade of ganoid scales for which the owner is not known (Brinkman, 1990). The shape of these scales are polygonal and measure from 2-3 mm at the widest axis. The articular edges of these scales have a unique peg and socket pattern characteristic of Holostean A designation.

TESTUDINES Linnaeus, 1758
 CRYPTODIRA Cope, 1868
 NAOMICHELYS Hay, 1908
 NAOMICHELYS SPECIOSA Hay, 1908

Description: A handful of carapace and plastron elements posses the diagnostic pustule ornamentation of this species. Specimens of this taxon from the Willow Tank Formation exhibit a regular distribution of pustules on the surface of the shell, identical to those of the type specimen (Ostrom, 1970). One element (VOF-2005-HBY-001) shows a reduction in the prominence of the pustules toward the edge of the costal plate. The pustules are ~1 mm in diameter in diameter with heights variable but always less than 1 mm. Overall thickness of the shell of this taxon ranges from 5 mm to 11 mm.

TESTUDINES Linnaeus, 1758

CRYPTODIRA Cope, 1868

BAENIDAE Cope, 1882

Description: This turtle taxon exhibits subtle ornamentation on the surface of the shell. There is a slight serpentine texture to the surface; however, surficial blood vessel canals are more prominent. All elements found for this taxon consist of shell material, with the exception of one element containing a portion of the pelvic girdle still articulated to the underside of the carapace. The acetabulum is saddle shaped and oriented so the open end of the saddle points nearly perpendicular to the axis of the neural column. Both acetabula are firmly fused to the shell. The length of the acetabulum parallel to the long axis of the shell is 17 mm; length perpendicular is 14 mm. The distance between the inner edges of the acetabula is 50 mm.

Surface ornamentation of the Willow Tank Formation specimens are reminiscent of, but less prominent than, *Glyptops* (Hay, 1908). The subtle ornamentation of the Willow Tank taxon is intermediate between the prominent *Glyptops* condition and the near lack of ornamentation of more derived baenids as figured in Hay (1908). This material was mostly recovered at site 3 with additional material found stratigraphically below site 1.

TESTUDINES Linnaeus, 1758

CRYPTODIRA Cope, 1868

TRIONYCHIDAE Grey, 1825

c.f. ADOCUS

Description: *Adocus* has been recognized in the Willow Tank Formation on the presence of several shell specimens possessing small, linearly arranged, dimples on the exterior. The best preserved specimen displays dimples parallel to the long axis of the costal, as

recorded in Hay's (1908) description of the genus. These specimens have a shell thickness of 8.5 mm making it much smaller than equivalent elements from the other two taxa found in the formation.

TESTUDINATA Linnaeus, 1758
CRYPTODIRA Cope, 1868
TRIONYCHIDAE? Grey, 1825

Description: Fragmented material has been assigned to trionychids. This material has a morphology like that of *Trionychus* rather than *Adocus*. *Trionychus* has a pitted surface ornamentation rather than dimpled like that of *Adocus*. This assignment is tentative as the material is not well preserved. Recovered specimens are less than a square centimeter in surface area and were recovered from dry screening at site 5.

CROCODYLIFORMES Benton and Clark, 1988
INDETERMINATE

Description: A number of crocodilian teeth recovered from screen sites and surface collection have been found from the Willow Tank Formation. These teeth are highly variable in size and shape, ranging from less than 3 mm in length to almost 3 cm.

Variations in morphology include; one morphotype is Morphology varies from having a blunt crown with a circular cross-section and faint striations down the length of the element, to a shape 2 cm long, slightly curved and with pronounced striations down the length. It can not be determined from which taxa these teeth belong. In addition to the teeth, one crocodilian osteoderm was recovered from site 4. The osteoderm is broken along two edges leaving a triangularly fragmented specimen. The surface ornamentation is irregular, with round to oval depressions. Each depression has varying widths ranging from 4 mm to 8 mm; depths vary from 3 mm to less than 1 mm. The underside possesses

two nutrient foramina and in cross section several annuli are observable.

DINOSAURIA Owen, 1842
SAURISCHIA Seeley, 1887
THEROPODA Marsh, 1881
DROMAEOSAURIDAE Matthew and Brown, 1922

Description: The material diagnosable to dromaeosaurids consists of a femur (lacking its distal end), a partial tibia, and some dromaeosaurid-like teeth. The recovered femur is 20 cm long from the head to the broken distal end. This specimen has undergone a small amount of lateral compaction as a result of burial. Despite being compacted, it still retains a bit of a bowed appearance, of which the concave side points medially, this condition is common in dromaeosaurs (Norrell and Makovicky, 2004). The femur possesses a posterior trochanter which Ostrom (1976) describes as an attribute of *Deinonychus antirrhopus*. A faint ridge runs from below the head lateriodistally across the posterior side of the femur. This feature can also be seen as a figure in Ostrom's (1976) description of *Deinonychus antirrhopus*. The highly, laterally compressed teeth bear serrations on their posterior margin only, as in other dromaeosaurs (Ostrom, 1976; Norrell and Makovicky, 2004). Both teeth are broken; however, posteriorly-anteriorly they measure 7 mm and 6 mm. Laterally, they both measure 3.5 mm.

SAURICHIA Seeley, 1887
THEROPODA Marsh, 1881
TYRANNOSAUROIDEA Osborn, 1905

Description: The presence of a tyrannosauroid is based on the identification of a single premaxillary tooth, possessing the diagnostic D-shaped cross-section (Holtz, 2004). The total length of the tooth from base to broken tip is 7 mm. The labial-lingual width at the base is 4 mm, while at the tip it is 2 mm. The lateral width of the tooth remains constant

at 3 mm. The lingual side of the tooth has a longitudinal keel, becoming more prominent distally. Carinae run on either side of the keel, separated by a groove. These carinae extend up the lateral edges of the tooth and possess very fine serrations, becoming less prominent toward the tip of the tooth. This tooth structure is diagnostic of all tyrannosauroid premaxillary teeth. As a result of this feature being an autapomorphy for tyrannosauroids, a more precise taxonomic diagnosis cannot be made.

SAURISCHIA Seeley, 1887
THEROPODA Marsh, 1881
INDETERMINATE

Description: Numerous other theropod teeth have been found in the Willow Tank Formation; however, their taxonomic identification cannot be made below this level. All unidentifiable theropod teeth have been recovered from the sites 3, 5, and 10. In addition to the teeth, theropod egg shell has been recovered from sites 5 and 12. Diagnosis is based upon SEM imaging of a cross section of the shell which reveals a multilayer microstructure (Frankie Jackson pers. comm., 2006).

SAURISCHIA Seeley, 1887
SAUROPODOMORPHA Huene, 1932
TITANOSAURIFORMES Salgado, Coria, El Calvo, 1997

Description: A single tooth indicate the presence of sauropods in the Willow Tank Formation. The tooth is 8 mm from base to tip and has a basal diameter of 2.5 mm. It flares slightly distally before tapering, measuring 3 mm at the widest point. A triangular wear facet is visible on the lingual side of the tip, the facet is 1.5 mm at its widest point and extends ~1 mm down the length of the tooth. Presence of a subcylindrical cross-section and the lack of both labial grooves and a lingual cavity are diagnostic features

shared with Titanosauriformes (Upchurch et al., 2002). Retention of a triangular wear facet is further indicative of a basal titanosaouriform (Barrett et al., 2002).

ORNITHISCHIA Seeley, 1888
 ORNITHOPODA Marsh, 1881
 IGUANODONTIA Dollo, 1888

Description: Ornithopod teeth appear to represent both Iguanodon and iguanodontian grade taxa with the Willow Tank Formation. Both tooth morphotypes fit characteristics of the dentition of Iguanodontia (Norman, 2004). Several teeth approximately 2-3 cm in length, possess two keels running up the labial side. The double keel separates basal iguanodontian from more derived hadrosaurian teeth. The more derived, hadrosaur grade teeth bear a single keel running their length. These more derived teeth tend to be approximately 2 cm long and less robust than the basal forms. Further, the presence of an advanced iguanodontian of hadrosaur-grade is confirmed by a recently discovered dental battery. This specimen, collected after completion of fieldwork for this study, displays teeth stacked three-deep within a tooth family. The Willow Tank Formation includes teeth representing iguanodontids, definitely represented by an Iguanodon-grade and possibly also represented by a more advanced iguanodontian, such as a hadrosaurid-grade.

Material collected from site 11 includes a pubis, unprepared centrum, and portions of several ribs, possibly representing an associated skeleton. This locality has the potential to produce more material as the excavation is continued in the next field season. The pubis consists of a prepubic process and acetabular region. From the acetabulum, the process first tapers to its narrowest dorsoventral dimension (89 mm), and

then flares more distally. The length from the acetabulum to the broken distal end of the process is 36 cm. The expanded distal end of the prepubic process is indicative of *Iguanodontoidea* (Norman, 2004).

ORNITHISCHIA Seeley, 1888
 THYREOPHORIDAE Nopsca, 1915
 INDETERMINATE

Description: The material assigned to the thyreophorans include one complete tooth and several partial teeth. The complete tooth has a blade-like crown with a basal keel, indicative of thyreophoran teeth (Norman et al., 2004). These tooth characters can not diagnose this element to any lower level.

The first thyreophoran tooth fragment was recovered from site 4 but was poorly preserved. Additional material was discovered while wet screening sediments from site 5.

Plantae

PTERIDOPHYTA
CLADOPLEBIS

Description: The first fern morphotype, the longest yet incomplete specimen, has a rachis measuring 55 mm long with pinna coming off of that. The longest of the pinna is 24 mm, the pinna become increasingly shorter toward the distal end of the rachis. The pinna have an undulating texture composed of secondary pinna being up to 1 mm in amplitude. Morphotype 1 (Fig. 11D) is consistent in morphology to the morpho-genus *Cladoplebis* (figured in Tidwell, 1998).

MATONIA

Description: A second fern morphotype consists of a rachis with pinna, the longest incomplete specimen is 42 mm. The pinna are roughly the same length, 24 mm, from proximal to distal end of the rachis. Pinna are completely attached to the rachis.

Morphotype 2 (Fig. 11E) is consistent with *Matonia* (figured in Tidwell, 1998).

InvertebratesMOLLUSCA
GASTROPODA.

Description: A single gastropod shell was recovered from site 10. Total length of the shell is 11.5 mm; the spire of this specimen is 3 mm to tip. The aperture is 8 mm long and sinistral. This gastropod was the only invertebrate specimen found during the entirety of this study.

Traces*Scoyenia* ichsp.

Description: This ichnotaxon determination is based on serpentine traces which leave positive topographic relief, with concave back fillings. The traces are approximately 5-8 mm wide, the distance between spreite is 1-2 mm. Most of the traces are parallel to the bedding of the sandstone. Samples were recovered as float and epirelief or hyporelief were not noted. Three specimens were recovered from the North of Tear Fault Mesa locality in the vicinity of site 10. *Scoyenia* is interpreted to be the trace formed from beetle larva feeding through the sandstone substrate (Hasiotis, 2002).

Site 10 is the only locality in the study which has produced any trace fossils, these

traces were found in a channel sandstone bed. Only the one ichnogenus is presently known.

Coprolites

Description: A number of coprolites have been recovered from site 3 and from a small exposure, coprolite mountain, near site 5. These specimens range from ovoids having a diameter of 1-2 cm wide and long axes of up to 3 cm to larger (~5-6 cm) specimens which show sphincter striations. Several coprolites have been found to contain ganoid scales.

Discussion

Exposures of the Willow Tank Formation have produced 16 taxa, including invertebrates, plants, dinosaurs, crocodilians, turtles, and fish. These taxa are nearly evenly distributed between terrestrial groups and semi-aquatic to aquatic groups. The dinosaur assemblage consists of a dromaeosaurid, tyrannosauroid, titanisauriform, possibly two iguanodontians, and thyreophoran. The turtle assemblage is relatively diverse with at least 3, possibly 4, taxa. Also present are at least three types of fish represented by two types of ganoid scales and dipnoan tooth plates. The presence of invertebrates is documented by a trace fossil and by a single gastropod shell.

The taxa present within the Willow Tank Formation are consistent with those found in other major Lower Cretaceous formations from North America (Table 4 & 5). Early Cretaceous faunas across North America appear rather homogenous at the family level, with dinosaur taxa seemingly consistent across the continent (Gilmore, 1922;

Ostrom, 1970; Winkler, 1990; Kirkland et al., 1997; Kirkland et al., 1998). Two genera of turtles occur in the majority of these formations. *Glyptops* is found in the Arundel Formation of Maryland (Hay, 1908), the Cloverly Formation of Montana and Wyoming (Ostrom, 1970), the Cedar Mountain Formation of Utah (Kirkland et al., 1997), and in the Trinity Group of the southern coastal plain (Nydam et al., 1997). The other widespread genus of turtle, *Naomichelys*, has been recorded in all but the Cedar Mountain Formation (Ostrom, 1970; Nydam et al., 1997; Kranz, 1998). *Naomichelys* is not found in the Lower Cretaceous section of the Cedar Mountain Formation, it is restricted to the Upper Cretaceous Mussentuchit Member (Cifelli et al., 1999).

While shared dinosaur taxa may not be that surprising due to the ability of large bodied organisms able to move large distances, it is surprising to see turtles with large biogeographic ranges. Typically, turtles are used to interpret subtle biogeographic boundaries which may be passable by larger, more mobile taxa (Lipka et al., 2006). Some dinosaur taxa found in Africa are also found in South America and these, in turn, are related to European taxa (Naish et al., 2004). In contrast, the Gondwanan turtle assemblage, dominated by Pleurodires, and the Laurasian turtle assemblage, dominated by Cryptodires, during the Early Cretaceous (Hirayama et al., 2000) did not overlap ranges. In short, the dinosaur taxa could move across these continents while the taxa of turtles were incapable of such dispersal, implying a biogeographic boundary of some sort. For the two turtle taxa found in the Early Cretaceous of North America to have such a wide distribution is significant, implying that climatic conditions across the continent were equable or possibly these two taxa of turtle were broad generalists. Modern turtles

with a generalist approach in North America have larger ranges than more specialized species (Heenan, 1999), but even more generalist taxa do not have ranges wider than 3,000 km E-W or N-S (Heenan, 1999).

Some of the dinosaur taxa present in the Willow Tank Formation are important temporally and possibly biogeographically. The Willow Tank Formation is radiometrically dated to the very end of the Albian (Troyer et al., 2006). The presence of the tyrannosauroid tooth from the Willow Tank Formation is significant because previously the earliest occurrence of tyrannosauroids in North America during the Cretaceous is in the uppermost Mussentuchit Member of the Cedar Mountain Formation (Kirkland et al., 1999), which straddles the Albian-Cenomanian boundary. Another interesting occurrence in the Willow Tank Formation is the presence of iguanodontid teeth in addition to more derived hadrosaurid-like teeth. In other Albian aged formations of North America, *Tenontosaurus* is the common iguanodontian (Ostrom, 1970; Nydam et al., 1997; Kranz, 1998, Kirkland et al., 1999). In the Willow Tank Formation there is no evidence for *Tenontosaurus*. The occurrence of hadrosaurid-like teeth in the Willow Tank Formation implies a relationship to the upper, Mussentuchit member of the Cedar Mountain Formation, whereas, the occurrence of iguanodontid teeth implies a relationship to the basal Yellow Cat member. To further confound matters, dromaeosaurids have been recovered throughout the Cedar Mountain Formation (Kirkland et al., 1999); dromaeosaur material has also been recovered from the Willow Tank Formation which is most similar in size to *Deinonychus*, though not enough material has been recovered for a positive assignment to that taxon. *Deinonychus* is

found only in the middle, Ruby Ranch member of the Cedar Mountain Formation (Kirkland et al., 1999).

The dinosaur taxa of the Willow Tank Formation have affinities with all three members of the Cedar Mountain Formation, with the tyrannosauroid-hadrosaurid material having affinities for the latest Albian-early Cenomanian member; the medium sized dromaeosaurid being most similar to dromaeosaurs from the Albian member; and the iguanodontid material being most similar to the Aptian-Albian member. A titanosauriform tooth recovered from the Willow Tank Formation is consistent with titanosauriform material recovered from the lower two members of the Cedar Mountain Formation as opposed to the lack of titanosauriform material from the upper member. Also absent from the Willow Tank Formation, of the taxa recovered from the Mussentuchit member of the Cedar Mountain Formation are pachycephalosaurids, ceratopsids, and troodontids (Cifelli et al., 1999). This discrepancy in taxa may reflect the current limited sampling of the Willow Tank Formation.

If the Willow Tank Formation is slightly older than the Mussentuchit member of the Cedar Mountain Formation, as radiometric dates suggest, then the first appearance of tyrannosauroids and basal hadrosaurids in the Cretaceous of North America took place in the Albian, not at the Albian-Cenomanian boundary. Fossil material is found stratigraphically throughout the Willow Tank Formation. Many of the above mentioned taxa come from a single locality so there is little chance of time averaging across the interval of all three members of the Cedar Mountain Formation. The patterns suggest possible multiple immigration events from Asia, the first including tyrannosauroids and

hadrosaurids with subsequent immigration events involving ceratopsids, pachycephalosaurs, and troodontids.

The Willow Tank Formation assemblage shows a similar taxonomic composition as the Lower Cretaceous formations of North America, implying that there was not a large enough ecological disparity between the Atlantic Coast, Gulf Coast, Northern Plains, Central Utah to the Sevier Fold Thrust front to significantly affect the megafauna or microvertebrates. Further investigation and more precise assignment of taxa, with addition of floristic data may allow patterns to become more apparent. At this time, it is evident that the biogeography of the Early Cretaceous vertebrate assemblage of North America is nearly homogenous, at the higher level of taxonomic resolution possible for the Willow Tank Formation.

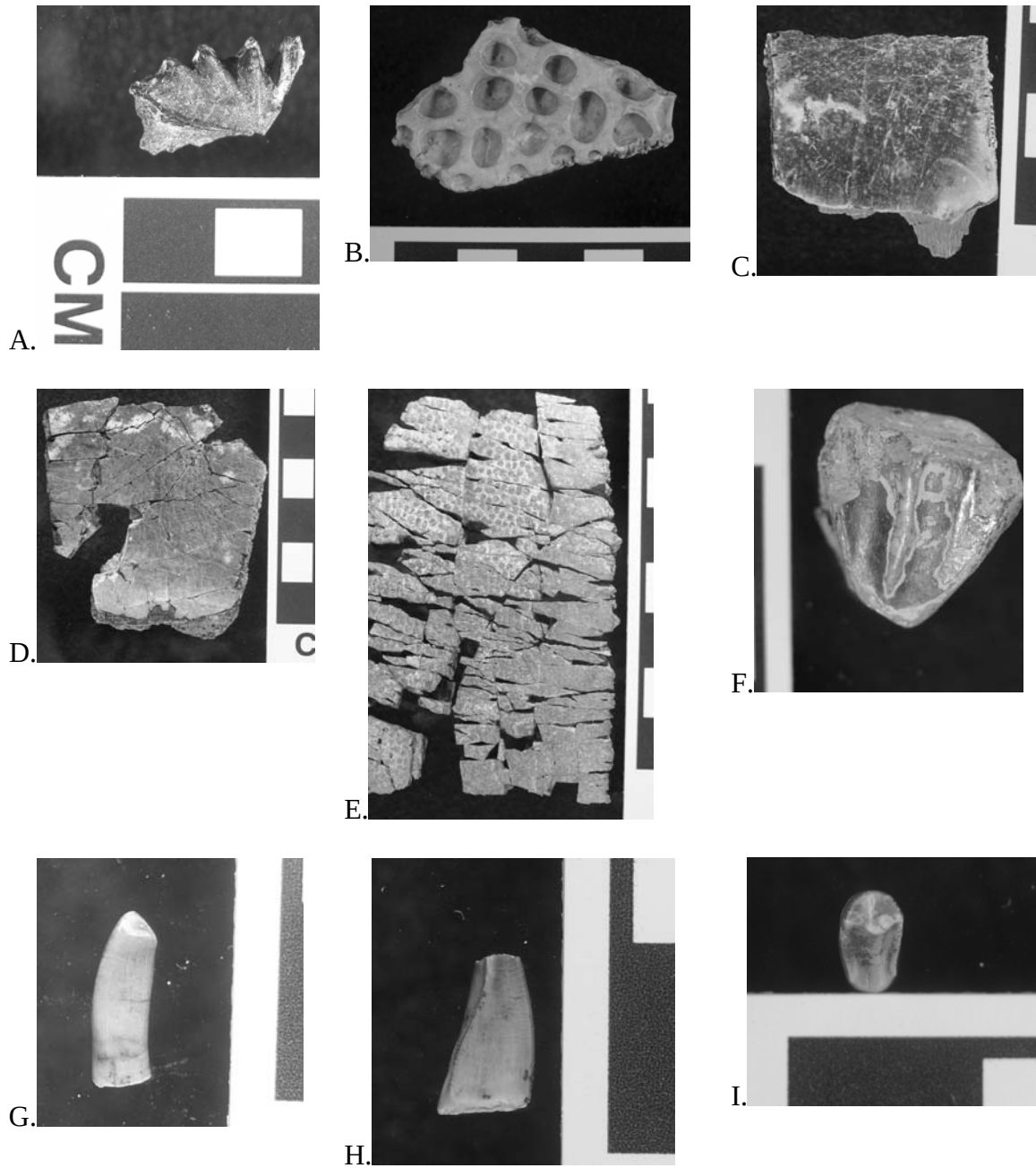


Figure 10. Photos of select specimens described above. A. Less robust *Ceratodus* tooth. B. Crocodilian scute. C. *Adocus* costal fragment. D. Baenid costal fragment. E. *Naomichelys* costal fragment. F. Iguanodontid tooth. G. Titanosauriform tooth. H. Lateral view of Tyrannosauroid tooth. I. Occlusal view of same Tyrannosauroid tooth.

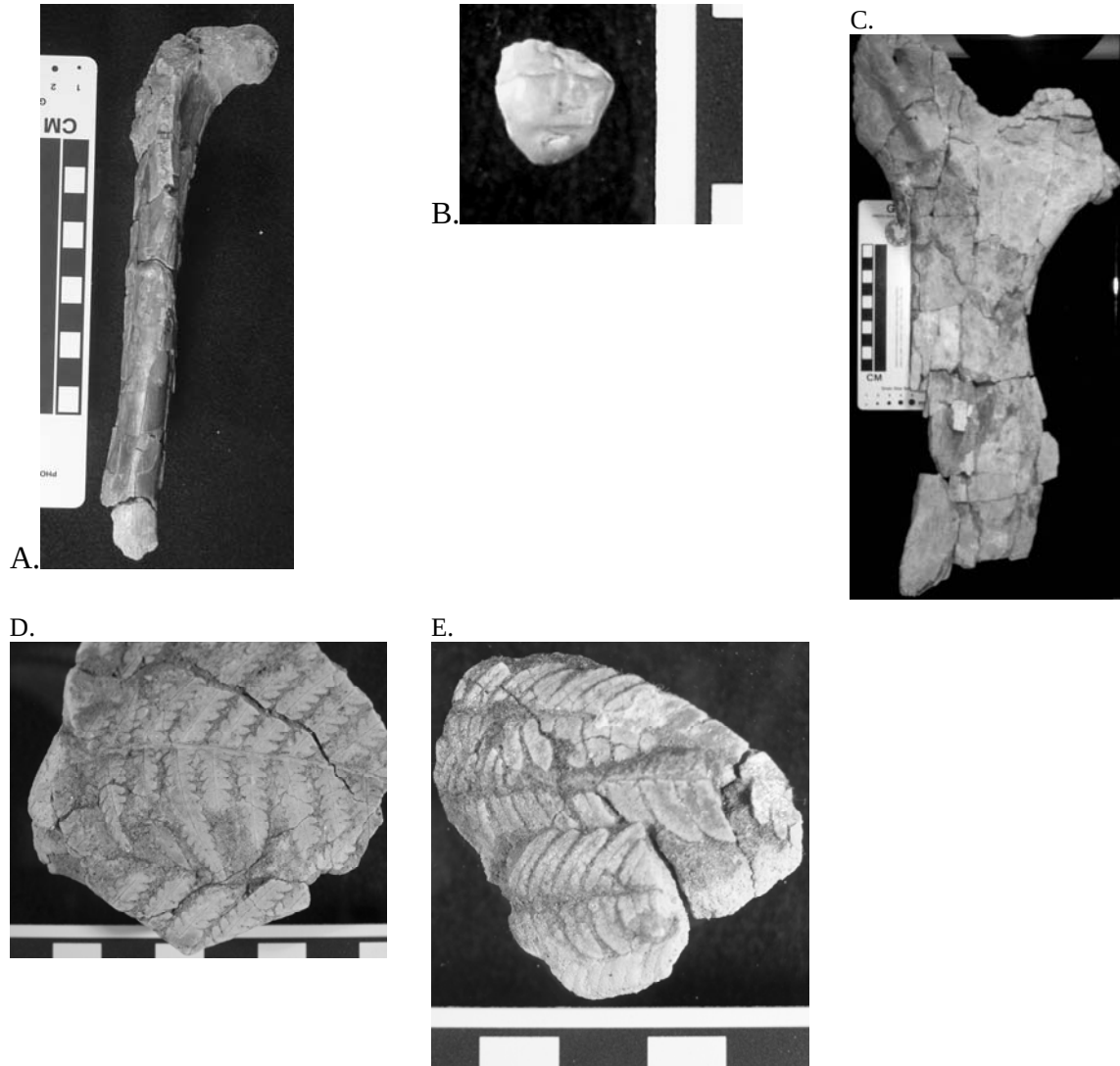


Figure 11. Photos of select specimens described above. A. dromaeosaur femur, B. Thyreophoran tooth, C. Iguanodontian pubis, D. *Cladoplebis*, E. *Matonia*.

TAPHONOMY

Fossil localities from the Willow Tank Formation represent a number of taphonomic modes (Table 6) consistent with fluvial depositional environments (Behrensmeyer et al., 1992). Fossil material occurs throughout the upper member of the Willow Tank Formation and in almost every type of lithofacies, including volcanoclastic and siliciclastic facies. There has been no evidence of fully articulated specimens and only three localities (Site 3, Site 10, Site 11) contain any associated specimens. The fossil bearing beds of the study area represent attritional and event assemblages. Details for the specific sites of collection are covered below in numerical order.

Site Descriptions

Site 1 is a sandy mudrock horizon (Fsm) with highly abundant carbonate nodules. Fossils recovered from Site 1 are fragmentary and highly weathered (Stage 3) to the point that no identifiable elements have been recovered.

Site 2 is a microsite found in a sandy mudrock (Fsm) bed, stratigraphically positioned between two crevasse splay sandstone beds. Collection was done by surficial prospecting and wet screening. This site was largely unproductive; yielding only crocodylomorph teeth and highly weathered (Stage 3) bone fragments.

Site 3 occurs within a sequence that proceeds, stratigraphically, through volcanoclastic (Vc), mudrock (Fm), fine sandstone (Sm) with mud clasts, and mudrock (Fm). This sequence sits low within the upper member of the Willow Tank Formation, yet above the medial ash horizon (Vc). The volcanoclastic horizon is laterally traceable

from section 1 to section 3 to section 4. The lower mudrock unit is 0.3 m thick and is organic rich, with a dark brown color and slight petrochemical scent. The sandstone with mud clasts is 0.4 m thick and is the main fossiliferous unit. The overlying mudrock unit is 4 m thick and exhibits pedogenic features, including caliche nodules, mottling and reddening toward the top of the bed. This mudrock unit contains occasional, isolated turtle shell fragments. There are no channel sandstone bodies near this site and the only observable sandstone upsection is crevasse splay deposits (Sm and Sh).

The majority of elements recovered from the sandstone represent turtle carapace and plastron material. The turtle shell fragments were discovered in clusters of up to 5 fragmentary elements in close proximity, with occasional articulated elements (Appendix A). The fragmentary nature of elements is due mostly to post burial breakage as exhibited by blocky breakage. Most shell fragments show a life like orientation, the carapace pieces are convex up and the outer surface of plastron pieces are down. These elements range from no abrasion to low-moderate abrasion (stage 0-2, Brand et al., 2000). Excavated material exhibited no prefossilization weathering. There are no bite marks on any of the shell material. Dinosaur, crocodilian and dipnoan teeth occur strictly at the base of the bed with the turtle shell elements. Ganoid scales were found both scattered vertically throughout the horizon as well as within coprolites. There were no elongate elements recovered from this site. Flat portions of the recovered turtle shell give no indication of flow. The only taxon which exhibits any articulation or association is the baenid. The *Adocus* and *Naomichelys* were found as isolated shell fragments. All other taxa are represented by isolated tooth or scale elements.

Table 6. Taphonomic modes of fossil bearing localities in study area.

Site	Lithofacies	Depo. Env.	Taxa	Material	Collection
1	Fsm	Overbank, paleosol	Indet.	Indet.	Surface
2	Fm	Overbank fines	Croc., indet.	Teeth, weathered bone	Surface, wet screen
3	Sm	Overbank fines	Theropod, ornithopod, croc., turtle, fish	Teeth, scales, shell elements, coprolites	Surface, excavation
4	Fsm	Overbank fines	Thyreophoran, croc., turtle, fish	Teeth, scales, shell elements	Surface
5	Fm	Overbank fines	Theropod, sauropod, ornithopod, thyreophoran, croc., turtle, fish	Teeth, scales, bone fragments, egg shell fragments, coprolites	Surface, wet screen, dry screen
7	Vc	Volcaniclastic/overbank	Ferns	Impressions	Surface
8	Fsm	Overbank fines	Indet. Dino., turtle	Bone fragments, shell element	Surface, excavation
9	--	Indet.	Indet.	Bone fragment	Surface
10	Fm	Overbank fines	Theropod, ornithopod, turtle	Teeth, bones, shell elements	Surface
11	Fm, Sh	Avulsed channel sandstone	Ornithopod, theropod	Associated skeletal elements, egg shell fragments	Surface, excavation
12	Fm	Overbank fines	Egg shell	Egg shell fragments	Surface

* Site 6 was identified during original survey but is outside of the boundaries of the Valley of Fire and therefore was not included in this study.

Table 7. Site 3 Taphonomy

<u>Taxon</u>	<u>NISP</u>	<u>MNI</u>	<u>Abrasion</u>	<u>Weathering</u>	<u>Articulation/Association</u>
<i>Ceratodus</i>	2	2	1	0	none
<i>Lepisosteid</i>	~10	1	1	0	none
<i>Holostean A</i>	~6	1	1	0	none
<i>Baenid</i>	~25	2	0-1	0	both
c.f. <i>Adocus</i>	2	1	0-1	0	none
<i>Naomichelys</i>	1	1	0-1	0	none
<i>Crocodylian</i>	2	1	1	0	none
<i>Ornithopod</i>	1	1	1	0	none
<i>Theropod</i>	1	1	1	0	none

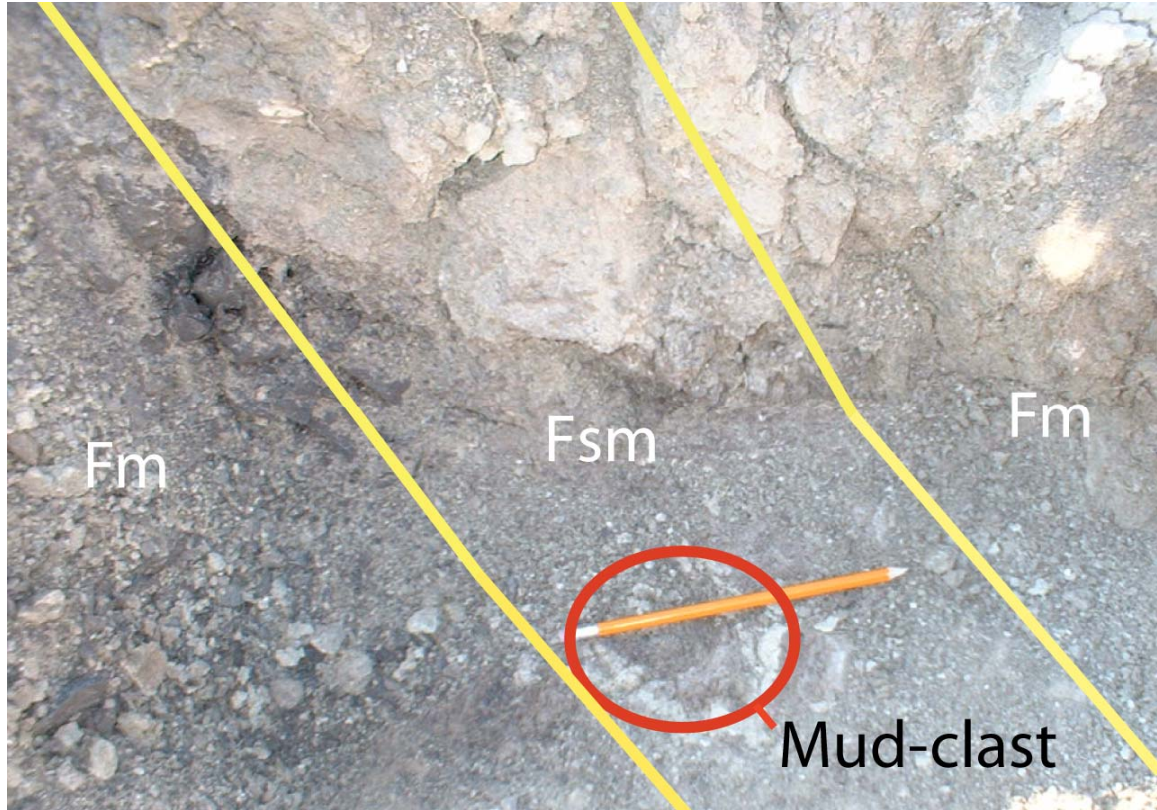


Figure 12. Stratigraphy of Site 3. White lines show boundaries of lithofacies, a mud rip-up is in the black circle. Pencil for scale.

Site 4 occurs only 400 m distant from site 3 and appears to represent the same stratigraphic horizon. However, Site 4 does not produce near the amount of fossil material as Site 3. Surface collection yielded ganoid scales, turtle fragments, a crocodylomorph scute, and a broken thyreophoran tooth.

Site 5 is a microsite which has produced teeth from crocodylomorphs and a minimum of 5 different dinosaur taxa. This site has also generated badly weathered (Stage 3) bone fragments, small vertebrae, occasional ganoid scales, turtle scutes, and egg shell fragments. This site produced both iguanodon-grade and hadrosaur-grade teeth. According to Behrensmeyer et al. (1992), time averaging on a floodplain represents 1-

10,000 years. Thus, this site shows that these two taxa occurred close temporally. The extracted vertebrate remains are dispersed with mud rip-up clasts occurring within a silty mudrock (Fm). Both the overlying and underlying beds of Site 5 possess characteristics of paleosol development with mottled red-green mudrocks and occasional carbonate nodules (Retallack, 2001).

Site 7 is comprised of plant macrofossils, represented by fern impressions preserved in Vc lithofacies. The fern impressions are rare, yet when present are exquisitely preserved making it possible to discern at least two morphotypes.

Site 8 yields a single *Naomichelys* costal along with fragments of thick (~2 cm) dinosaur bone. The dinosaur bone is badly weathered (Stage 2) and possesses fragments exhibiting blocky breakage. The turtle costal is well preserved (abrasion 1-2, Brand et al., 2000; weathering 0), it was only after exposure that the specimen broke into splinters then was reassembled in the course of preparation. The sediments at this locality are a massive siltstone (Fm).

Site 9 and Site 10 were both surface collected. Site 9 possessed a single dinosaur bone fragment which was chalky in texture and had already been fractured. This specimen (SOS5-1) was found in a small wash and is partially encased in a mudrock concretion. The fragmentary nature of this specimen prevents diagnosis to any lower taxonomic level than dinosaur. Site 10 produced an ornithopod tooth, a theropod femur and tibia, 2 theropod teeth, crocodylomorph teeth, and some small turtle shell fragments. The theropod femur was fragmented, exhibiting a blocky and spiral type fracture.

Site 11 has produced several potentially associated ornithopod elements. This

locality occurs at the top of an isolated channel sandstone body. The fossil specimens are stratigraphically positioned where the channel sandstone and mudrock are interstratified. The largest element recovered, a pubis, shows moderate to weak signs of abrasion (Stage 2) and weathering (Stage 1). A fair number of rib fragments, a nearly complete rib, and centrum were also recovered from this locality. Taphonomic data on this specimen is difficult to record as a result of modern weathering and root action on the specimen. In addition to the skeletal material, egg shell fragments were also discovered.

Site 12 or “Egg Shell site” was so deemed because of the exclusive presence of egg shell fragments found along the surface. Recovered fragments typically have a diameter of 2-4 mm. The two-layered microstructure of the eggshell identifies it as theropod in origin (Frankie Jackson pers. comm., 2006). The egg shell bearing horizon occurs at the top of a paleosol which is topped by a sheet sand body (Sh) up to two centimeters thick, which in turn is topped by a massive mudrock (Fm). The actual paleosol horizon shows red-green mottling in addition to abundant *in situ* carbonate nodules (Fig. 9).

Discussion

The fossil bearing localities within the study area represent deposition in a fluvial environment, including channel and floodplain settings. Most material was found in overbank deposits, the majority of which contain some sort of pedogenic features. Overbank deposits make up 9 of the 11 fossil bearing localities. These floodplain deposits are microsite accumulations with two exceptions, sites 3 and 8. Only one

channel deposit produced any vertebrate material, that being Site 11. The taphonomic mode of site 9 was indeterminate. Site 3 is consistent with the overbank deposits and is unique because it is the only locality which preserves a bone bed. Unlike most other sites, site 7 is volcanoclastic and remains unique as a taphonomic mode in the study area. Based upon elements recovered there is a bias in recovered elements toward aquatic or semi-aquatic taxa, such as turtles and fish scales. Most likely this is a product of a preservational bias given that these animals live in water. Taxonomically, the number of aquatic versus terrestrial organisms is nearly equal. Sites 2, 3, and 4 all contain a higher proportion of specimens from aquatic/semi-aquatic taxa. The other 8 sites are dominated by terrestrial taxa.

Most of the overbank sites are interpreted to be attritional assemblages based upon the fragmentary nature of the recovered specimens, and in the case of site 1 there is a high degree of weathering implying that these specimens were exposed to the environment for some time prior to burial. Specimens at site 1 are also found along with abundant pedogenic carbonate nodules suggesting that they were also exposed to pedogenic processes. One overbank site is not interpreted to be entirely attritional. Site 3 is interpreted to be an event deposit based upon the preservation of the fossils coupled with the sedimentology of the site. The turtle shell material recovered from the site all show minimal abrasion and weathering suggesting that these elements were all subject to a similar burial history. Any weathering of specimens is the result of modern processes. In actualistic studies of turtle taphonomy, it takes at least two weeks for a turtle shell to completely disarticulate (Meyer, 1991; Knell, 2004). Therefore, the articulated nature of

at least two individuals and associated nature of other elements suggests that some organisms were buried within two weeks of death. Other evidence supporting this site as an event deposit is that the turtle shell material is deposited with mud rip-up clasts composed of the underlying unit. In addition to the turtle specimens which represent recently dead individual, there is an attritional component to the assemblage. Dinosaur teeth, coprolites, and random turtle shell fragments are indicative of an attritional component to the site 3 assemblage (Rogers, 1993). The lack of weathering on turtle shell elements may represent subaqueous accumulation, weathering is primarily a subaerial process. Deposition was likely an event, however the assemblage represents both an event and attritional component.

Another unique site is site 11. This site represents a channel which was nearly avulsed. It was the reduced energy of the channel that allowed the specimen to remain associated and subsequently buried. Intermittent flow at this site is recorded by the interstratified Sh and Fm lithofacies at centimeter scale at the top of the channel sandstone body. The ornithopod material was likely exposed to the environment for at least a year based upon the amount of surficial weathering to the element. This is supported by actualistic studies of mammal bones in a semi-arid environment (Behrensmeyer, 1978).

Taphonomy of other Cretaceous formations also interpreted to be the products of proximal, anastomosed fluvial systems are dominated by overbank taphonomic modes (Nadon, 1993; Rogers, 1993). Anastomosed fluvial deposits from the Upper Cretaceous of the Sevier foreland record attritional death assemblages or mass death assemblages in

channel fills, channel lags, subaqueous microfossil concentrations, subaqueous bonebeds, subaerial bonebeds, and nest sites (Rogers, 1991; Rogers, 1993; Varricchio, 1995). The Willow Tank Formation does not record mass death assemblages; but it does record fossils in subaqueous microfossil concentrations, subaqueous bonebeds, and channel fills. Both Rogers (1991) and Varricchio (1995) interpret mass death assemblages of the anastomosed Two Medicine Formation (Lorenz and Gavin, 1984) as having accumulated around water sources during times of drought. This is not the pattern recorded in the Willow Tank Formation. Fossil bearing localities are not as rich as the Two Medicine examples. Nadon (1993) demonstrates that anastomosed fluvial environments are conducive to the preservation of egg shell and footprints. The Willow Tank Formation does preserve egg shell fragments in a similar sedimentological context as Nadon (1993) describes, however, there are no footprints recovered from the Willow Tank Formation thus far.

The preservation of vertebrate material in the Willow Tank Formation is fragmentary compared to material from the Cedar Mountain Formation and the Cloverly Formation. Both formations produce articulated large bodied organisms and microvertebrate localities (Ostrom, 1970; Maxwell and Ostrom, 1995; Kirkland et al., 1999; Eberth et al., 2006). This may reflect greater research on these other formations or the lack of good exposure of the Willow Tank Formation. Another possibility is that there may be lithology and depositional environmental differences between these different formations leading to the decreased likelihood of preservation in the Willow Tank Formation.

CONCLUSIONS

The Willow Tank Formation was deposited in the foredeep of the Sevier foreland basin (Schmitt and Kohout, 1986; Schmitt and Aschoff, 2003). Lithofacies of the upper member of the Willow Tank Formation consist predominately of mudrocks with interspersed sandstones. The majority of mudrocks represent overbank, floodplain fines and many possess pedogenic features such as carbonate nodules and reddening of units. Sandstone bodies represent two depositional environments, channel fills and crevasse splays. Channel sandstones are single storied and are lenticular in geometry and have abrupt contacts with overbank fine lithofacies. Crevasse splays are tabular in geometry and are laterally extensive. The channel sandstones have a higher width:thickness ratio than crevasse splay sandstones.

The prevalence of overbank deposits, distribution and geometry of sandstone bodies, and location in a rapidly subsiding foredeep are all consistent with models (Makaske, 2001; Wang et al., 2005) of deposition in an anastomosed fluvial system. The persistence of limestone clasts in the basal member (Reese, 1989) and the presence of calcareous soils in both members are indicative of a seasonally semi-arid to arid climate (Mack et al., 1993). Reddening of overbank mudrocks is consistent with a well drained floodplain (Behrensmeyer et al., 1992).

The vertebrate fauna of the Willow Tank Formation consists of dinosaurs (tyrannosauroid, dromaeosaur, titanosauriform, iguanodontian, and thyreophoran), turtles (*Naomichelys*, baenid, *Adocus*, and trionychid?), crocodylomorphs, and fish (bearing ganoid scales and *Ceratodus*) (Table 6). Other vertebrate remains include coprolites and

theropod egg shell. Invertebrate remains are rare but include one gastropod, a feeding trace (*Scoyenia*), and two fern morphotypes.

The fauna of the Willow Tank Formation is most similar to the Lower Cretaceous section of the Cedar Mountain Formation (Tables 2 and 3). When the dinosaur taxa are compared to the Cedar Mountain Formation, temporal relationships become confused. Iguanodontid and titanosauriform teeth resemble Albian faunas from the Cedar Mountain Formation (Kirkland et al., 1999) and the Cloverly Formation (Ostrom, 1970). tyrannosauroid and more derived iguanodontian teeth (i.e. hadrosaur-grade) resemble the latest Albian-early Cenomanian upper member of the Cedar Mountain Formation (Cifelli et al., 1999). Turtle occurrences in the Willow Tank Formation expand the geographic ranges of all three taxa to the fold and thrust front. Thus, *Naomichelys* and *Glyptops*-like turtles had geographic ranges which were continent-wide and exceed any modern turtle distribution. Turtles are susceptible to more subtle biogeographic boundaries than larger animals, this Early Cretaceous pattern is an interesting biogeographic distribution with unknown implications.

Taphonomic modes of the Willow Tank Formation are predominantly overbank depositional environments. All but two fossil localities in the study area are found in overbank sediments. Fossils are found in channel fill, subaqueous microsite, subaerial bonebed, and subaqueous bonebed assemblages. Taxa recovered from the Willow Tank Formation come from two microsites, two quarries, and surface collection. The majority of the fossil material recovered from the Willow Tank Formation is fragmentary and isolated, with few exceptions. Preservation ranges from partially articulated and

unweathered to isolated and unidentifiable. Taphonomic modes include microsites on well-drained flood plain, impressions in volcaniclastic sediments, a bonebed in an overbank deposit, and an associated specimen in a channel fill. All of these modes are consistent with preservation in a fluvial environment (Behrensmeyer et al., 1992).

APPENDICES

APPENDIX A

QUARRY MAP OF SITE 3



Quarry Map of Site 3. Rows are labeled 1-10 from south to north. Columns are labeled A and B, west to east.

APPENDIX B

A REVIEW OF TURTLE TAPHONOMY

Unlike other vertebrates, shell ornamentation allows turtles to be differentiated to a surprisingly low taxonomic level based upon fragmentary remains. This level of taxonomic resolution based on fragmentary material is especially useful for paleontological studies where entire specimens are not always recovered. This review is broken up into three sections: 1) the ecology of modern turtles, 2) actualistic experiments on modern turtle taphonomy, and 3) taphonomic studies on fossil turtle assemblages. The taphonomy of turtles presents an interesting problem because of the distinctive ecology and morphology of these organisms.

Today turtles are found on every continent, except Antarctica, and are present in the Pacific, Atlantic, and Indian oceans (Ernst and Barbour, 1987). In addition turtles occupy ecological niches in the open ocean, lakes, rivers and in wholly terrestrial settings. This diversity has led to their long term survival and success as a group (Ernst and Barbour, 1987).

To understand the ecology of prehistoric turtles it is instructive to have a working knowledge of the ecology of contemporary turtles, especially since their body plans and, presumably, their life histories have not changed significantly. Turtles lay both large clutches (e.g. sea-turtles) (Hatase et al., 2003) and small clutches, of only one (pers. observ.) to two eggs (Converse et al., 2002). Turtles begin their lives with a low chance of survival (Hellgren et al., 2000; Tucker and Janzen, 1999). As a result of the decreasing likelihood of predation and the greater ability to acquire resources, survivability increases with increasing size and age (Hellgren et al., 2000; Tucker and Janzen, 1999).

Turtles can often occur in large monospecific groups, especially during nesting season (Doody et al., 2003; Donaldson and Echternacht, 2005). Doody et al. (2003) observed groups of up to 12 *Carettochelys insculpta* individuals grouped together along nesting beaches in a stream. Alternatively, they may exist in multispecific amalgamations as they do in ponds (Stone et al., 2005). Stone et al. (2005) observed an average of three species of turtle in ponds in their study area. Nevertheless, some taxa live relatively solitary lives; for example desert tortoises come together only to mate (Kyle Snyder of Southern Nevada Environmental Inc. pers. comm., 2005).

Turtles have a wide range of predators depending upon which habitat the species occupies. In terrestrial ecosystems, turtles are preyed upon by raccoons, canids, varanids, and birds (Tucker and Janzen, 1999; Doody et al., 2003). In marine ecosystems, potential predators include sharks, fish, crocodilians and killer whales (Pitman and Dutton, 2004; Meyer, 1991; Sutherland and Sutherland, 2003). Furthermore, a large number of birds (i.e. vultures) and crustaceans may scavenge turtle carcasses (Meyer, 1991; Knell, 2004; Pitman and Dutton, 2004).

Though it is hard to summarize the ecology of such a large group of organisms, there are some central themes to keep in mind when applying the modern ecology of turtles to interpreting the taphonomy of long dead fossilized turtles. Some variables include: sociability, the diversity and abundance of predators, habitat, and survivability.

There are a few actualistic studies of modern turtle carcasses. Meyer (1991) and Knell (2004) performed actualistic experiments on marine turtle carcasses. Meyer (1991) observed that in a subaqueous environment just off shore from a beach, it took six days

for the first signs of disarticulation of a carapace and that by 17 days all bone sutures were open. This study (Meyer 1991) further noted that when turtles became stranded on beaches at high tide, crustaceans begin to scavenge the carcass and the cranial and non-shell elements began to disarticulate, although the carapace remained intact.

Knell (2004) observed vultures as the first significant scavengers of stranded marine turtle carcasses. When dead sea turtles washed ashore, vultures scavenged the head and neck region of the turtle carcass first in order to reach the internal organs. As with Meyer (1991), Knell (2004) also noted scavenging by crustaceans. Two species of sea turtle showed a consistent disarticulation pattern. Disarticulation began with the pedal and manual elements and then the neck and crania within a few days; disarticulation of the limb bones followed.

Freshwater turtles also show a similar pattern of disarticulation, with the skull and appendicular elements disarticulating long before the shell (Brand, 1994). Tucker and Janzen (1999) noted during their survey of modern freshwater turtles, that discovered dead turtles never possessed their cranial or appendicular elements.

Blob (1997) conducted a flume experiment testing for differences in the hydrodynamic attributes of soft-shelled turtle elements. Using fully disarticulated and defleshed elements he documented the critical water velocity required to move various elements by placing them in the flume at different orientations to flow (Blob, 1997). Although the carapace and plastron are the most often recovered elements of fossil turtles, they do not require the highest water velocities to be transported. Blob's experiment tested individual elements and did not take into account the pattern of

disarticulation of the turtle (Blob, 1997). Given the abundance of plastron and carapace elements in the fossil record, disarticulation patterns appear to have a greater influence on element abundance than ease of transportability.

Knell (2004) reviewed marine turtle taphonomy of the Cretaceous interior seaway. He observed that in comparison to larger forms, smaller turtle taxa showed poorer preservation as a result of diagenetic mineral precipitation and dorso-ventral compaction. The better preserved larger taxa of turtle included a higher proportion of specimens with shark inflicted damage (Knell, 2004). One large specimen even showed sponge borings (Knell, 2004).

Because sea turtles have a long fossil record, their potential predators have changed over time. Modern sea turtles have a wide range of potential predators. It may be inferred that sharks and crocodilians preyed upon prehistoric turtles just as they do today; however, prehistorically there were ichthyosaurs, mosasaurs and potentially other predators. Kear et al. (2003) describe finding the remains of hatchling sea turtles in the gut contents of an ichthyosaur, Meyer (1991) reports crushed and bite-marked turtle bone from the Jurassic of Switzerland, damage probably inflicted by crocodiles.

Taphonomic studies of freshwater turtles are limited to sites with unusually large assemblages (Wood, 1998; Brand et al., 2000). Brand et al. (2000) describes a large stratigraphic horizon in the Bridger Formation of southwestern Wyoming where turtles represent the primary vertebrates. The vast majority of these specimens lack any appendicular or cranial material (Brand et al., 2000), consistent with actualistic data on disarticulation (Knell, 2004; Meyer, 1991; Tucker and Janzen, 1999). Brand et al. (2000)

interpret their turtle assemblage as a population that lived in a large lake/marsh environment. They suggested the turtles were killed as the result of fallout from a volcanic event. This was inferred from the uniform preservational state of the turtles as well as overlying volcanogenic sediments (Brand et al., 2000).

Modern turtles provide an excellent basis of taphonomic comparison to prehistoric turtle assemblages. When modern turtle ecology is taken into consideration, fossil turtle assemblages can be better explained. For example, finding three different turtle taxa in the same spot may seem odd, except when this phenomena is related to modern ponds where often three different species of turtles regularly co-exist (Stone et al., 2005). Actualistic studies of modern turtle remains also demonstrate the relative importance of preburial processes on the occurrence of preservable elements (Meyer, 1991; Knell, 2004). Despite the wide range of habitats which modern turtles occupy, turtle mortality consistently decreases with increasing size and age.

APPENDIX C

MEASURED STRATIGRAPHIC SECTIONS AND
CORRELATED STRATIGRAPHIC SECTIONS

Lithology Key for Stratigraphic Sections



Cover



Volcanoclastic



Mudrock



Sandy Mudrock



Siltstone



Massive Sandstone



Ripple Cross-laminated Sandstone



Trough Cross-bedded Sandstone



Horizontally-bedded Sandstone



Cross-bedded Conglomerate

CH

Channel Fill

CS

Crevasse Splay

FF

Floodplain Fines

Gl

Low-angle cross-bedded conglomerate

St

Trough cross-bedded Sandstone

Sh

Horizontally-bedded Sandstone

Sr

Ripple cross-laminated Sandstone

Fm

Massive Mudrock

Fsm

Sandy Mudrock

Fl

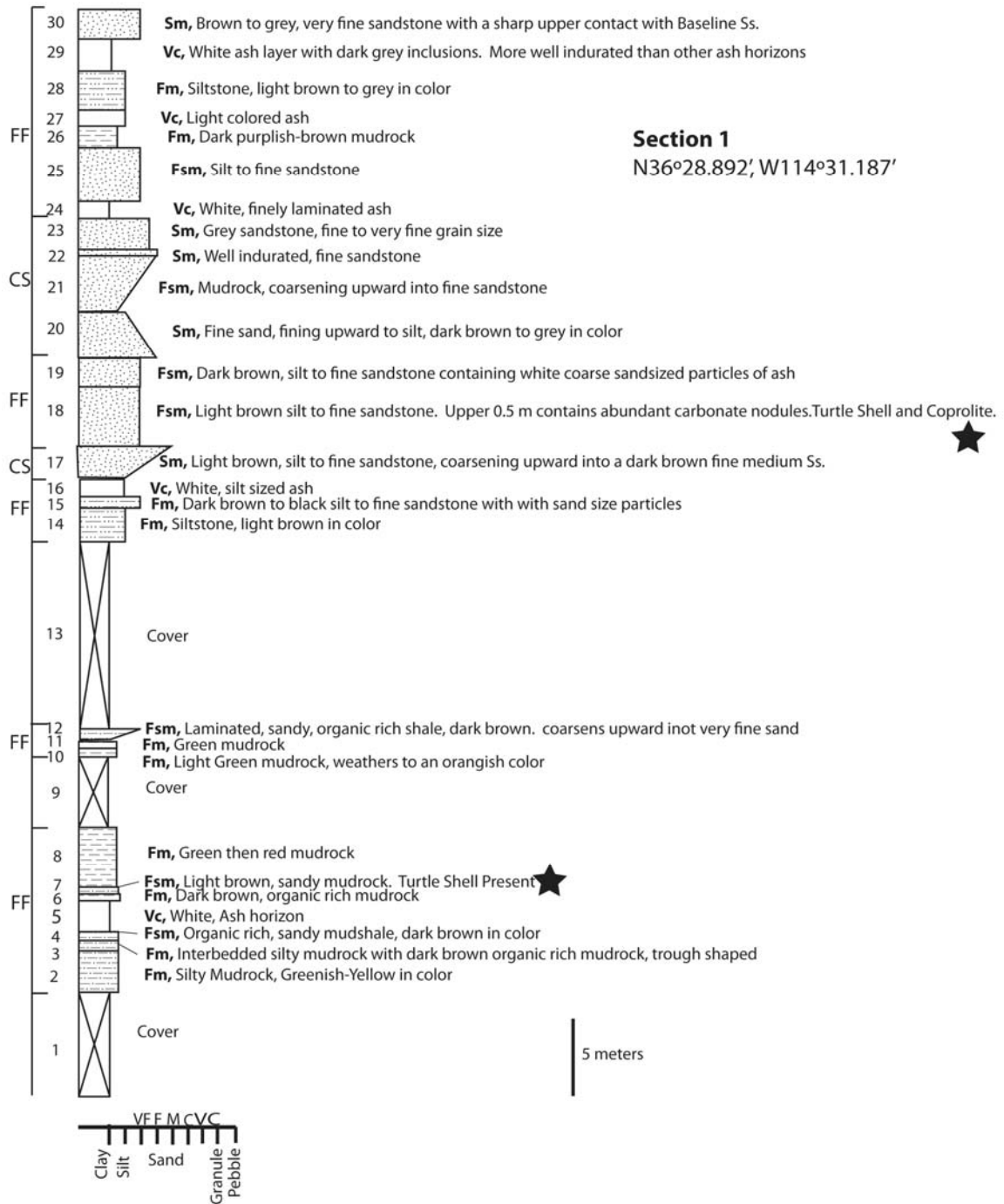
Clayshale

Vc

Volcaniclastic

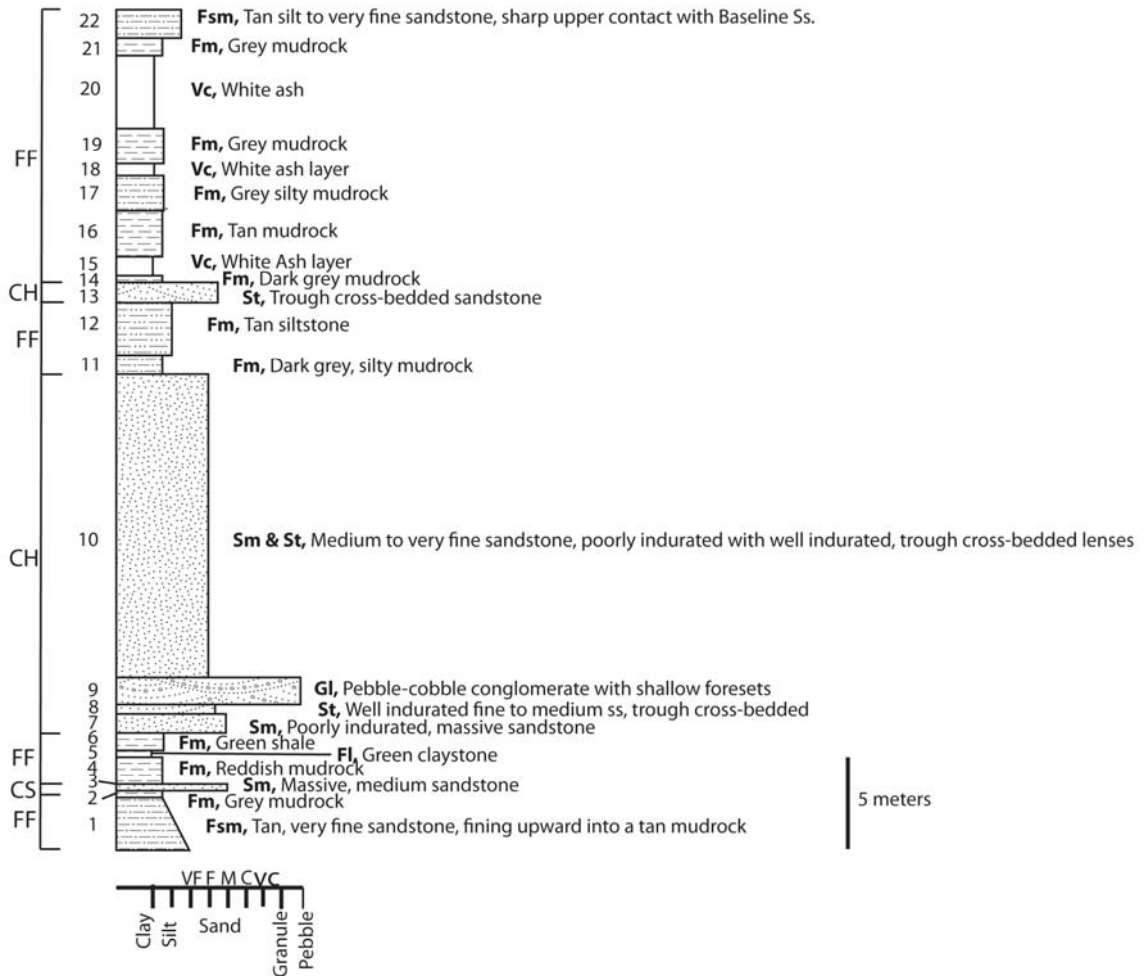


Fossil-bearing Horizon



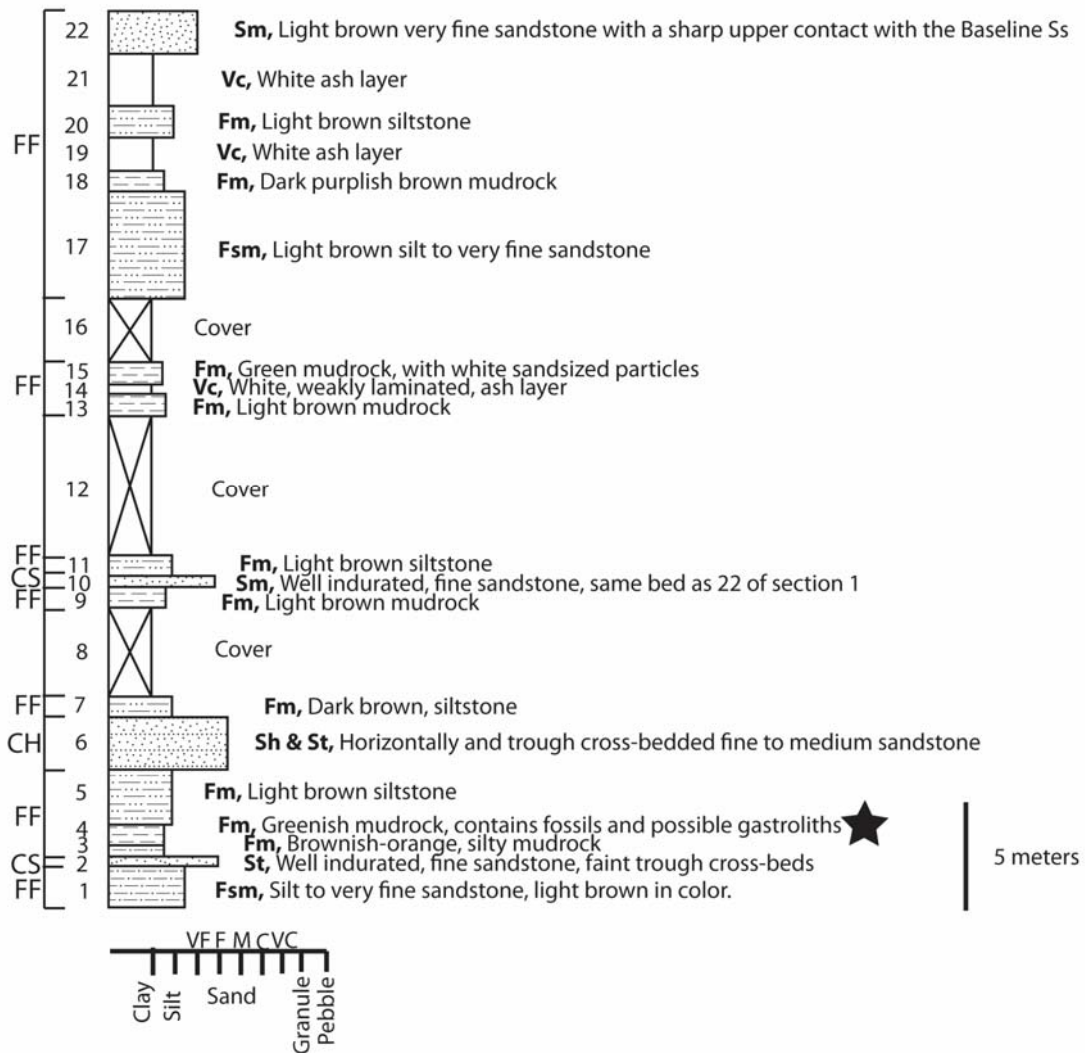
Section 1.5

N36°28.842', W114°31.133'



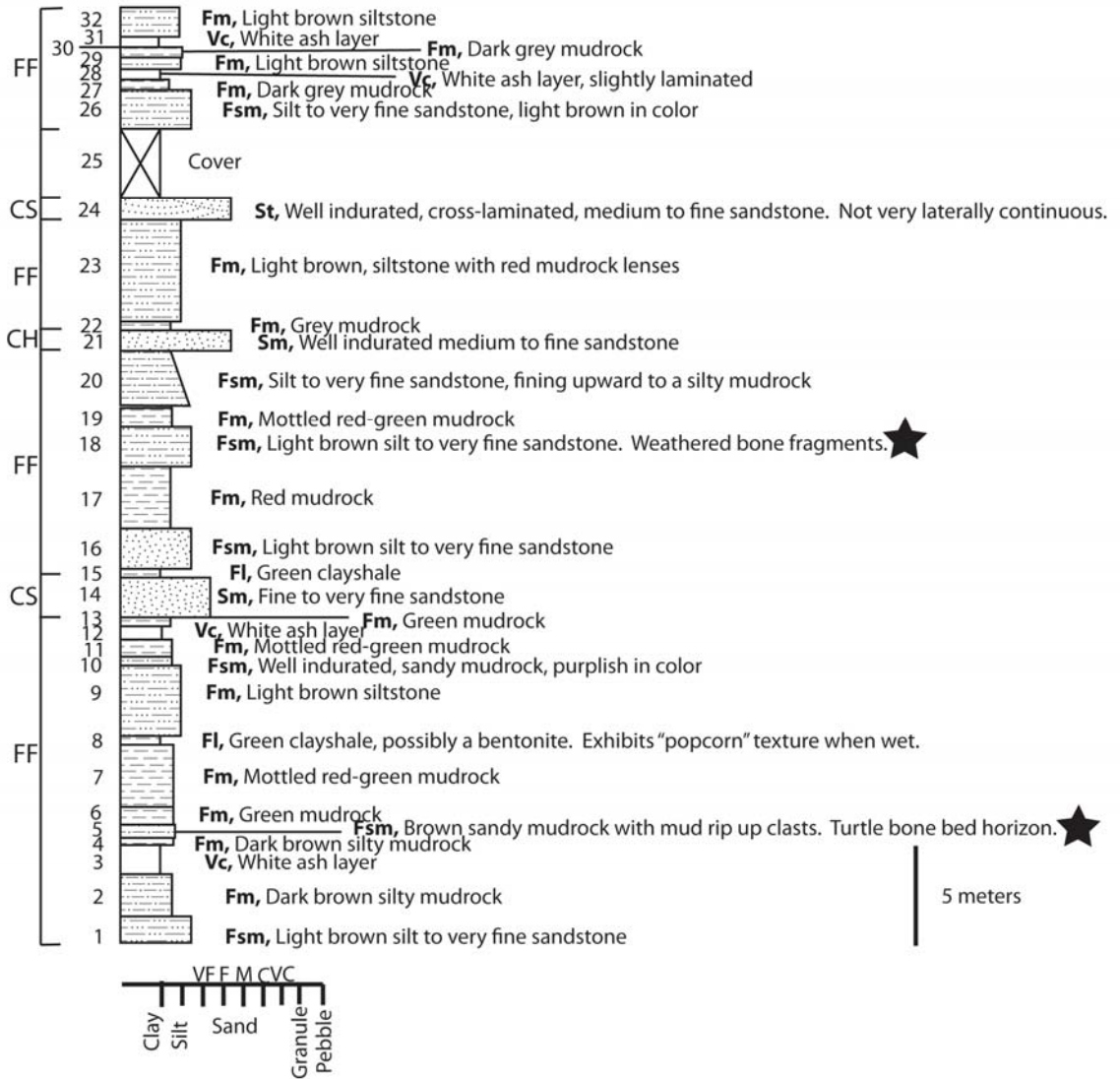
Section 2

N36°28.736, W114°31.086'



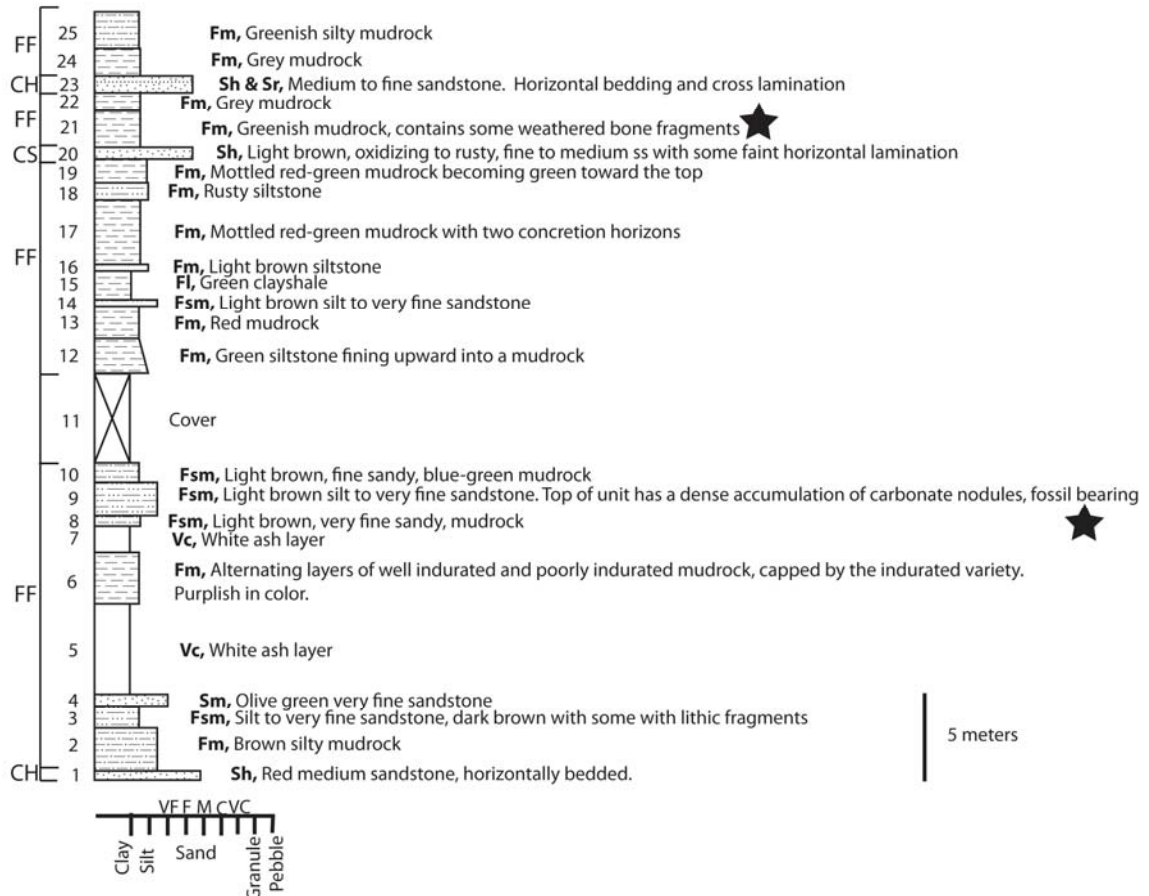
Section 3

N36°28.567', W114°31.029'



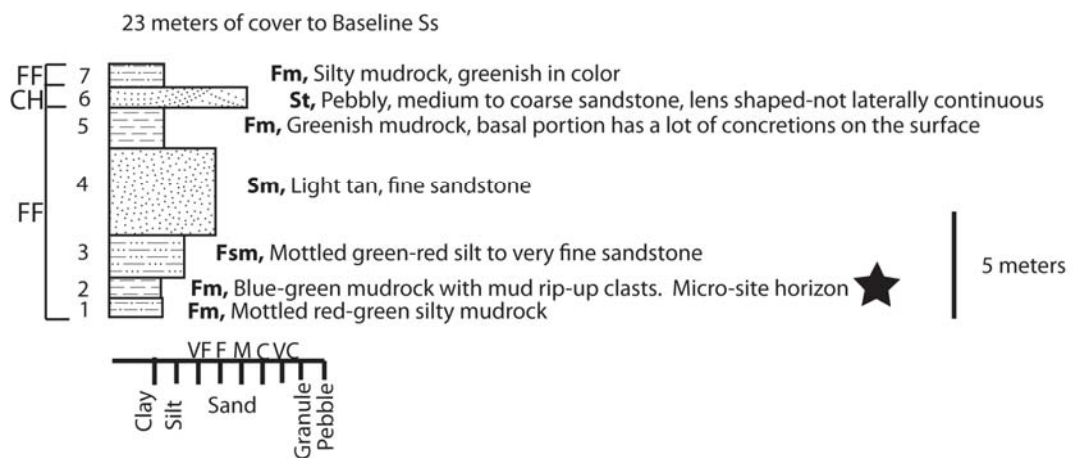
Section 4

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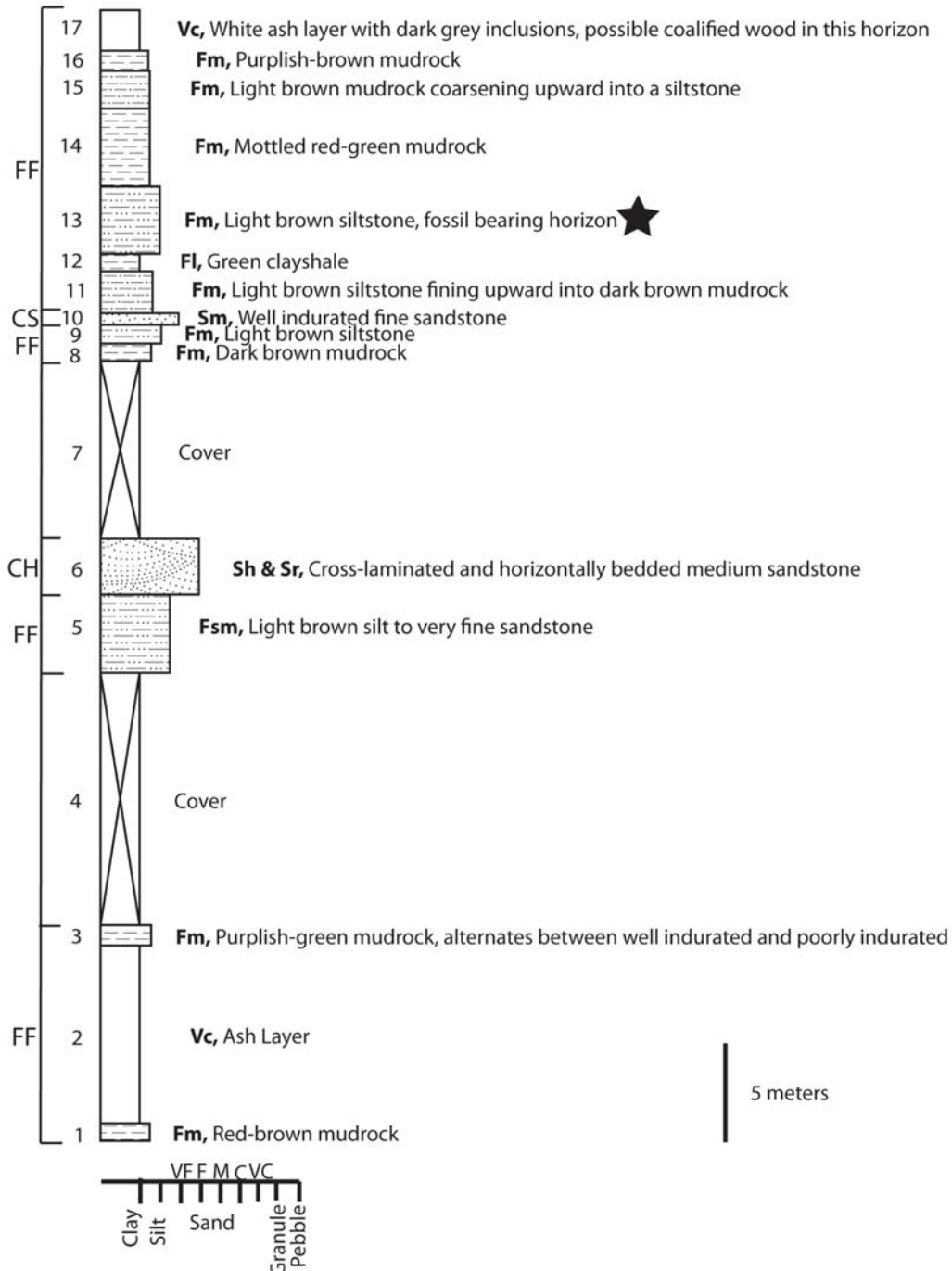
Section 5

N36°27.271', W114°29.670'



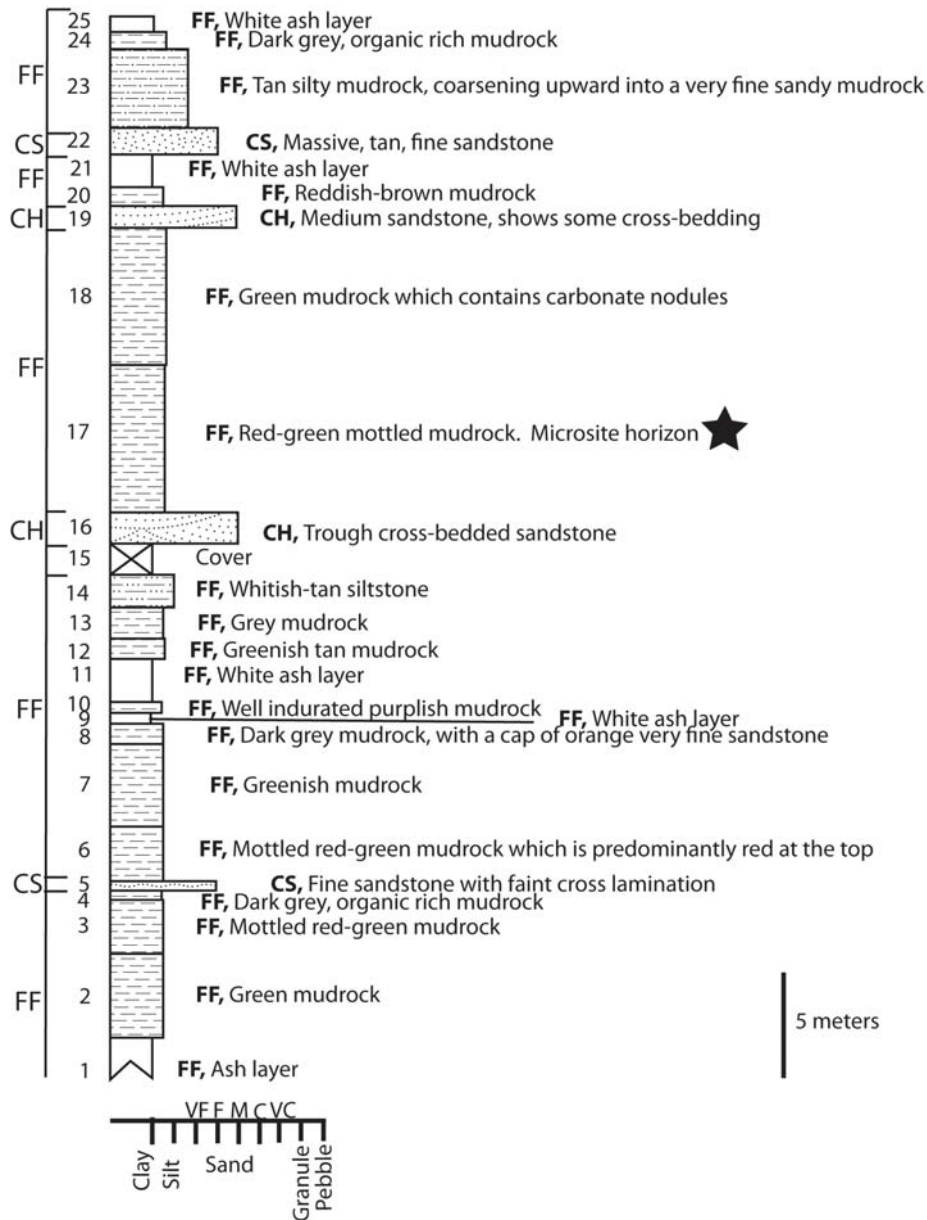
Section HBY

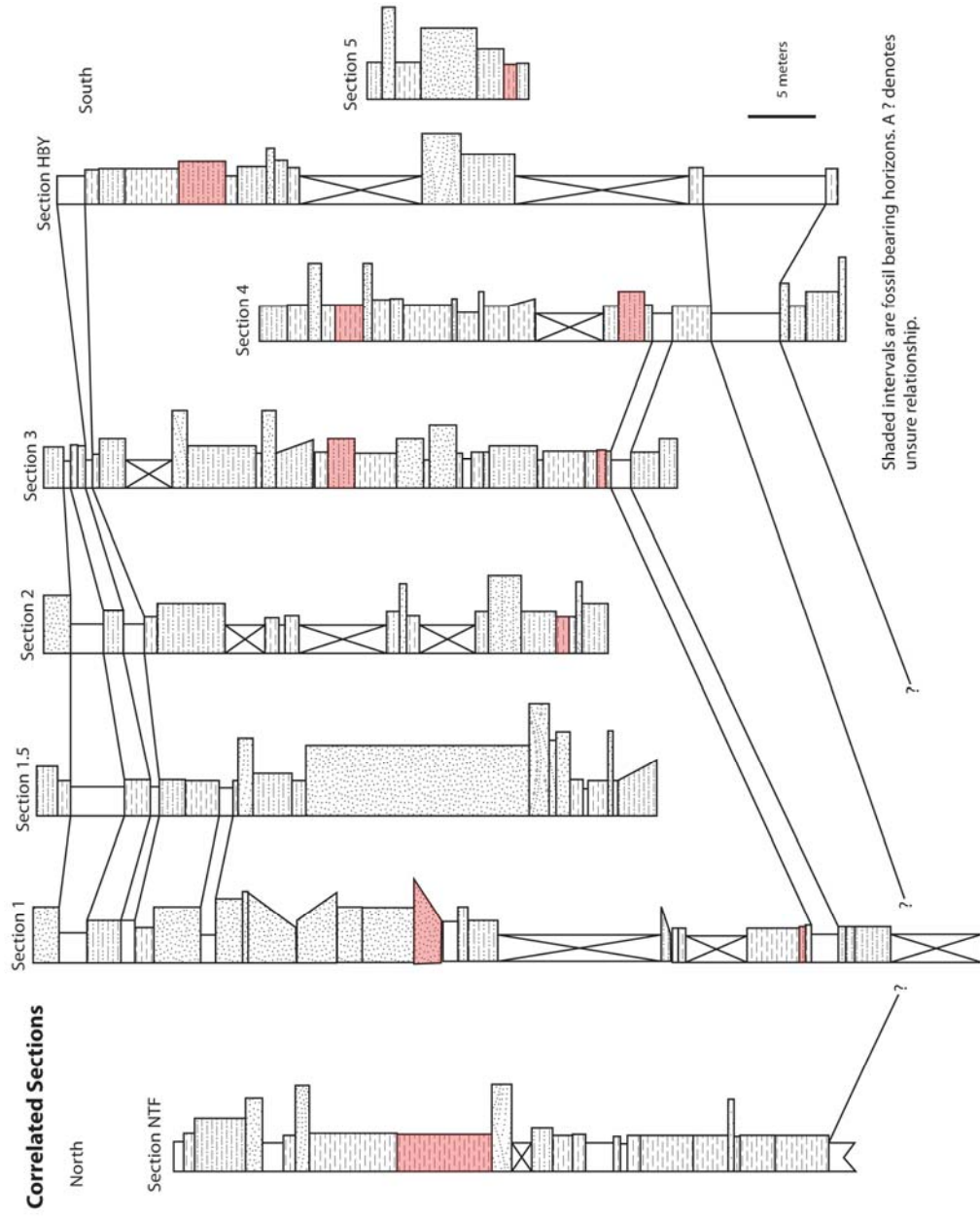
N36°27.883', W114°30.678'



Section NTF

N36°30.168', W114°31.431'





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