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From the Foreland to the Hinterland: Taphonomy across the Cretaceous to Paleogene Sevier Retroarc Region of Nevada

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FROM THE FORELAND TO THE HINTERLAND: TAPHONOMY ACROSS

THE CRETACEOUS TO PALEOGENE SEVIER

RETROARC REGION OF NEVADA

by

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A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy in Geoscience

Department of Geoscience
College of Science
The Graduate College

University of Nevada, Las Vegas
May 2012

THE GRADUATE COLLEGE

We recommend the dissertation prepared under our supervision by

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entitled

From the Foreland to the Hinterland: Taphonomy Across the Cretaceous to Paleogene Sevier Retroarc Region of Nevada

be accepted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Geoscience
College of Science

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May 2012

ABSTRACT

**FROM THE FORELAND TO THE HINTERLAND: TAPHONOMY ACROSS
THE CRETACEOUS TO PALEOGENE SEVIER
RETROARC REGION OF NEVADA**

by

Joshua William Bonde

Dr. Stephen M. Rowland, Examination Committee Chair
Professor of Geoscience
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Until 2004 very little paleobiology, let alone paleoecology, had been studied

within exposures of the Sevier retro-arc foreland and hinterland, in the state of Nevada.

This is due largely to poor and spotty exposure. This study focuses on taphonomic

processes within three stratigraphic intervals in the foreland and hinterland of the Sevier

retro-arc region, and what these taphonomic indicators reveal about the geography of the

hinterland.

First, the Willow Tank Formation of southern Nevada was deposited in the

foredeep of the Sevier retroarc foreland basin. This unit represents a multi-channel,

aggradational, fluvial system that drained the Sevier highlands to the west. High amounts

of volcaniclastic input have preserved a "snapshot" of a Late Cretaceous (Cenomanian)

flora *in situ*. Representative taxa include the ferns *Cladophlebis,* cf. *Matonia,* and

Tempskya; the horsetail *Equisetites*; the angiosperms *Magnolia* sp*., Sapindopsis

magnifolia*; as well as unidentified taxa. These taxa are represented by various organs

(leaves and stems) and are preserved in a manner which suggests rapid burial, likely in

less than a year. This floral record aids in paleoecological reconstructions of an area very

proximal to the Sevier fold and thrust front, a region not nearly as well documented as the

backbuldge of the Sevier fold and thrust front (i.e., Cedar Mountain Fm of Utah) of this time interval.

Second, the Newark Canyon Formation of east-central Nevada has been interpreted as the deposits of an Early Cretaceous (Aptian) piggy-back basin. This study identifies a diverse vertebrate assemblage which includes fish, turtles, crocodilians, armored dinosaurs, iguanodontid dinosaurs, and theropod dinosaurs. This fauna is hosted within small-channel sandstones, lacustrine mudrocks, debris-flow conglomerates, and hyperconcentrated-flow cobbly mudrocks. These depositional settings indicate a region with some internal drainage, as well as significant topography, but similar in elevation to the foreland, based upon similar small vertebrate taxa.

Finally, the Sheep Pass Formation [Late Cretaceous (Maastrichtian)-Eocene] is interpreted as Sevier hinterland deposits. Unlike the Newark Canyon Formation, the Sheep Pass Formation is considered to be deposits of a basin analogous to those of the modern, highland Altiplano of South America, in this case Nevadaplano. This is a long lived lake basin, with debris flow deposits and occasional fluvial input. From this formation I have recovered a diverse invertebrate fauna, a limited flora, and a vertebrate fauna consisting exclusively of frogs. The frogs are preserved in various taphonomic modes, including attritional assemblages, reworked elements, and a frog bonebed. The biological remains suggest an environment which was cool, at least seasonally. Occurring during a global climatic optimum, the inferred cool climate reinforces the conclusion that the Sevier hinterland was a high elevation plateau, which agrees with the stable isotope data from another study, as well as with structural studies.

ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

This dissertation comprises three separate studies that all share the central theme

of taphonomic settings within the Sevier Orogenic belt of eastern Nevada (Figures 1.1,

1.2). The timing of the Sevier Orogeny is debatable, but it is generally considered to have

begun during the Late Jurassic and terminated in the Paleogene (Figure 1.2) (DeCelles,

2004, and references therein). I wrote these three studies as individual chapters, suitable

for individual submission to technical, peer-reviewed journals. This introductory chapter

will serve as a review-style paper to introduce readers to the research question, field of

taphonomy, and the geologic setting of the Sevier Orogeny.

Research Question

Does the biotic record of Nevada during the Sevier Orogeny agree with or

disagree with current interpretations of the paleogeography of the Nevadaplano?

Taphonomy

The classic definition of taphonomy is that it is the study of an organism's

transition from the biosphere to the lithosphere (Efremov, 1940); however the field has

expanded through time to incorporate all biotic and abiotic factors which influence an

organism after death (Behrensmeyer et al., 1992). In general, taphonomic data are

gathered in the field and lab, including map orientation of elements, articulation and/or

association of elements, as well as bone-bone contacts, lack of contacts, complete

disassociation, breaks, break style, and alteration halos. In the lab, and after the

preparation of elements, surface modification data are obtained, because modification is

often obstructed by matrix (Eberth et al., 2007). Surface modification data include

weathering (Behrensmeyer, 1978), abrasion (Shipman, 1981), tooth marks, bioerosion, trample marks, and the nature of breaks (e.g., faults, blocky, spiral). Trend and plunge data are used to determine whether elements have been aligned, which suggests the influence of fluid flow, or whether they are randomly oriented. Random orientation of bones may reflect rapid burial (Eberth et al., 2006) or trampling (Fiorillo, 1989). Further, studies of modern coyote and sheep bones by Voorhies (1969) show that bones with a "heavy" end tend to orient themselves with the "heavy" end pointing upstream in the case of fluid flow. Orientation data are displayed in a rose diagram if the majority of elements are within 5° of horizontal; if elements are largely $>5^\circ$ from horizontal orientation, data are analyzed with a stereonet (Eberth et al., 2007).

Weathering is used as a proxy for how long an element was exposed on the surface. Behrensmeyer (1978) conducted a study documenting how bones weather through time. She established a rank system from 0-5 to classify different states of weathering on elements. According to her system, a greasy bone with fresh surfaces is a "0", whereas a deeply cracked bone in which all cortical bone is gone is a "5" (Behrensmeyer, 1978). Degree of weathering, in addition to being used as a measure of the length of time bones have been exposed on the surface, is used to determine time-averaging of an assemblage. If different elements from the same assemblage show different degrees of weathering, one can infer that the assemblage accumulated over a relatively long time interval, on the order of seasons to decades (Behrensmeyer, 1978).

Abrasion, like weathering, is used to determine the degree of time-averaging of an assemblage. If different elements show different degrees of abrasion, they likely reflect a mixed assemblage, or elements of variable provenance and age. Shipman (1981)

established a rank system of 0-3 to characterize levels of abrasion, with "0" representing pristine bone and "3" being bone with the ends completely rounded off. Abrasion is also directly related to transport mechanisms; the higher the degree of abrasion, the further a given element has been transported. Abrasion data can thus be used to determine relative site fidelity of an assemblage.

Trample marks are recognized as sub-parallel scoring of bones (Eberth et al., 2007). If elements possess trample marks, the assemblage is probably time-averaged. Trample marks can also be environmental proxies; riparian habitats experience minor amounts of trampling whereas water hole sites are intensively trampled (Eberth et al., 2007).

Tooth marks on bones are tell-tale signs of carcass processing and evidence of direct interactions between organisms. Different types of tooth marks are pits, punctures, scores, and furrows (Eberth et al., 2007, and references therein). Pits are depressions in cortical bone; punctures are depressions which go through the cortical bone; scores are sub-parallel marks along a bone where teeth were dragged across the surface of the bone; and furrows are scalloped or ragged edges of bone resulting from intense bone processing (Eberth et al., 2007 and references therein). In some cases the identity of a bone processor may be established (Haynes, 1980; Haynes, 1983; Dominguez-Rodrigo and Piqueras, 2003).

Bioerosion refers to processes such as etching by plant roots and boring by invertebrates; evidence of such processes can shed light on the paleoecology of the site, such as whether the area was heavily vegetated. Breakage patterns can reveal whether bone was broken fresh (spiral) or weathered/mineralized (blocky) (Eberth et al., 2007).

Bone is not usually broken during fluvial transport, so any broken bones in a fluvial assemblage can be assumed to have entered the system broken as a result of biogenic or physical processes (Behrensmeyer, 1982).

All of these processes are taken into account to understand the biases which exist in a fossil assemblage. I employed these taphonomic methodologies in each of the three chapters that follow.

Geological Settings within the Sevier Orogeny

The Sevier Orogeny is characterized by thin-skinned thrust faulting and resultant crustal thickening in the Sierra Nevada retroarc region, as a result of Jurassic to Paleogene subduction of the oceanic Farallon Plate beneath the western margin of North America (Figure 1.3) (DeCelles, 2004, and references therein). Following maximum crustal thickening in the Late Cretaceous, east-central Nevada is generally envisioned as part of a high-elevation orogenic plateau, termed the Nevadaplano (Coney and Harms, 1984; Jones et al., 1998; Dilek and Moores, 1999, DeCelles, 2004).

Each of the three formations examined in this study is found in a different geological setting within this contractional orogen. The Willow Tank Formation (Chapter 2) represents the only one of these formations that lies within the Sevier retroarc foreland (Figure 1.3). The Willow Tank Formation consists of terrestrial deposits of a multi-channel, aggradational, fluvial system which drained the Nevadaplano to the west, and which was deposited within the foredeep of the foreland (Schmitt and Kohout, 1986; Reese, 1989; Schmitt and Aschoff, 2003; Bonde et al., 2008). The Newark Canyon Formation (Chapter 3) is interpreted to have been deposited within a wedgetop, piggy-back basin (Figure 1.3) (Vandervoort and Schmitt, 1990). Newark Canyon Formation deposits represent through-flowing fluvial deposits as well as major lacustrine units

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(Vandervoort and Schmitt, 1990; Druschke et al., 2011). The focus of the final study, the Sheep Pass Formation (Chapter 4), represents the deposits of a synconvergent, extensional basin which, at the time of deposition, was high up on the orogenic Nevadaplano plateau (Figure 1.3) (Druschke et al., 2009a,b). Each of these formations, occupying a different position within the orogenic belt, has a unique suite of taxa preserved, and exhibits distinctive taphonomic modes. The focus of this research is the documentation of the taphonomic history of each of these three tectonic settings within the Sevier retroarc region of Nevada, and to document if these taphonomic settings can shed light on the paleogeography of Nevada during this orogenic event.

Hypothesis

The Null Hypothesis is that the biota of the Aptian Newark Canyon Formation, Cenomanian Willow Tank Formation, and Maastrichtian-Eocene Sheep Pass Formation were deposited at the same elevation.

If this is true, then preservational modes should be similar between all three units. If all units were deposited at a similar elevation, then I expect the biota to be comparable as well as the preservational modes which preserve the organismal remains.

An alternative hypothesis is, that each unit was deposited at different elevations. If this hypothesis is true, then I would expect to see disparate preservational modes between units. If biota which are climatically and ecologically sensitive are differentially preserved between units, then I would expect that elevation would have played a roll in altering the local environments which would allow or not allow those organisms to survive, perish, and become preserved. The null and alternative hypotheses will be revisited at the end of each chapter.
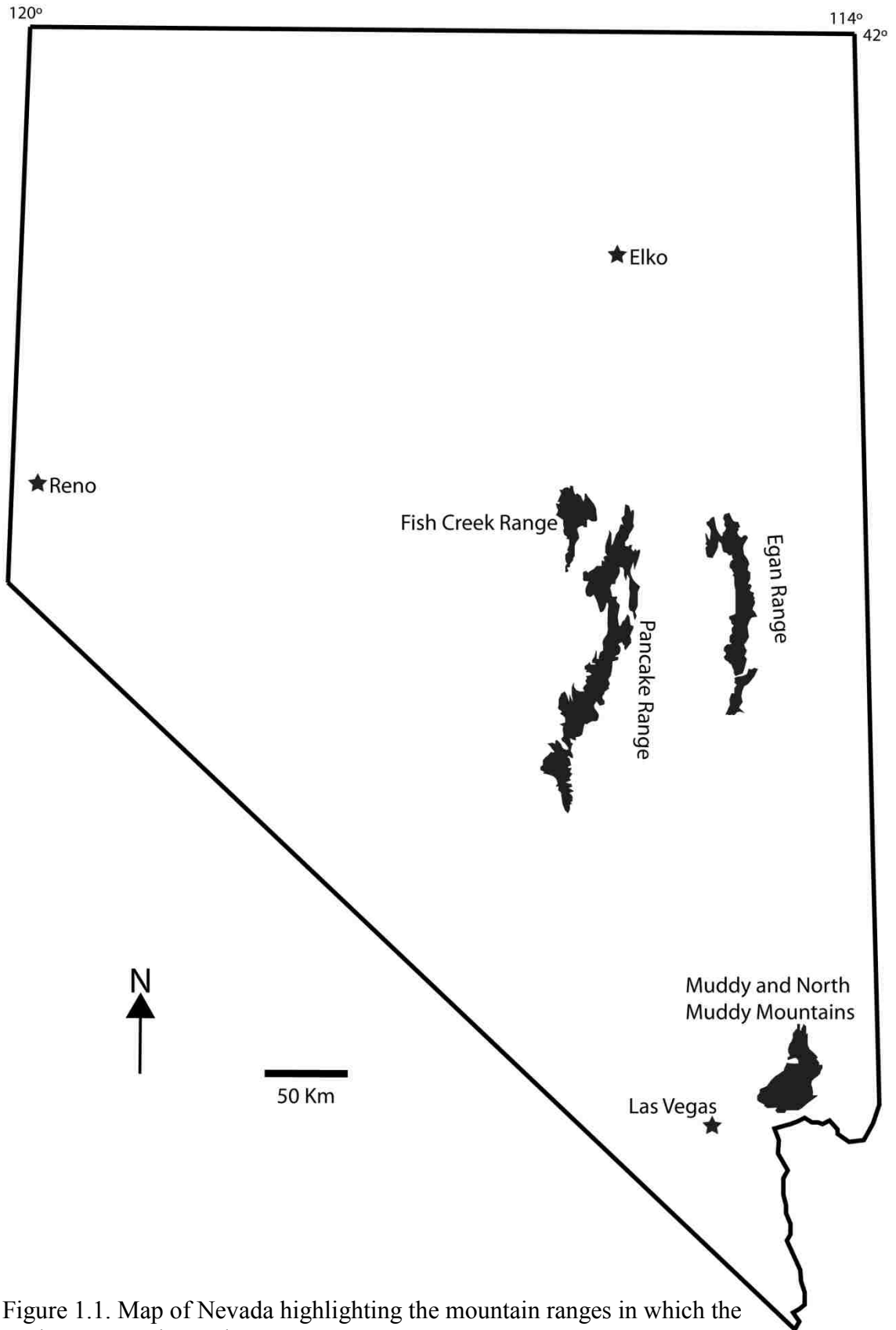
Figure 1.1. Map of Nevada highlighting the mountain ranges in which the study areas are located.
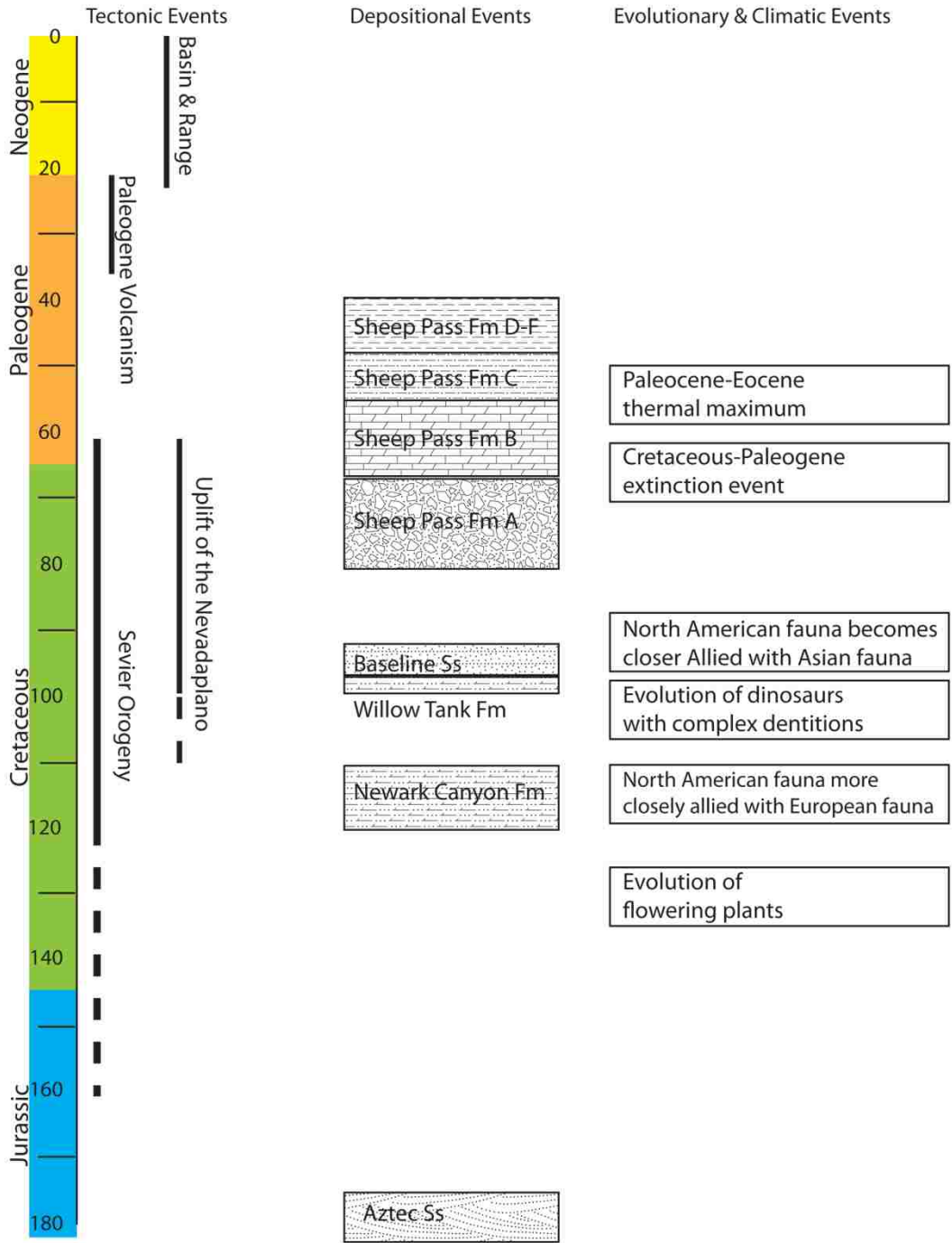
Figure 1.2. Sequence of tectonic, depositional, climatic, and evolutionary events with direct impact on the Cretaceous and Paleogene of Nevada.
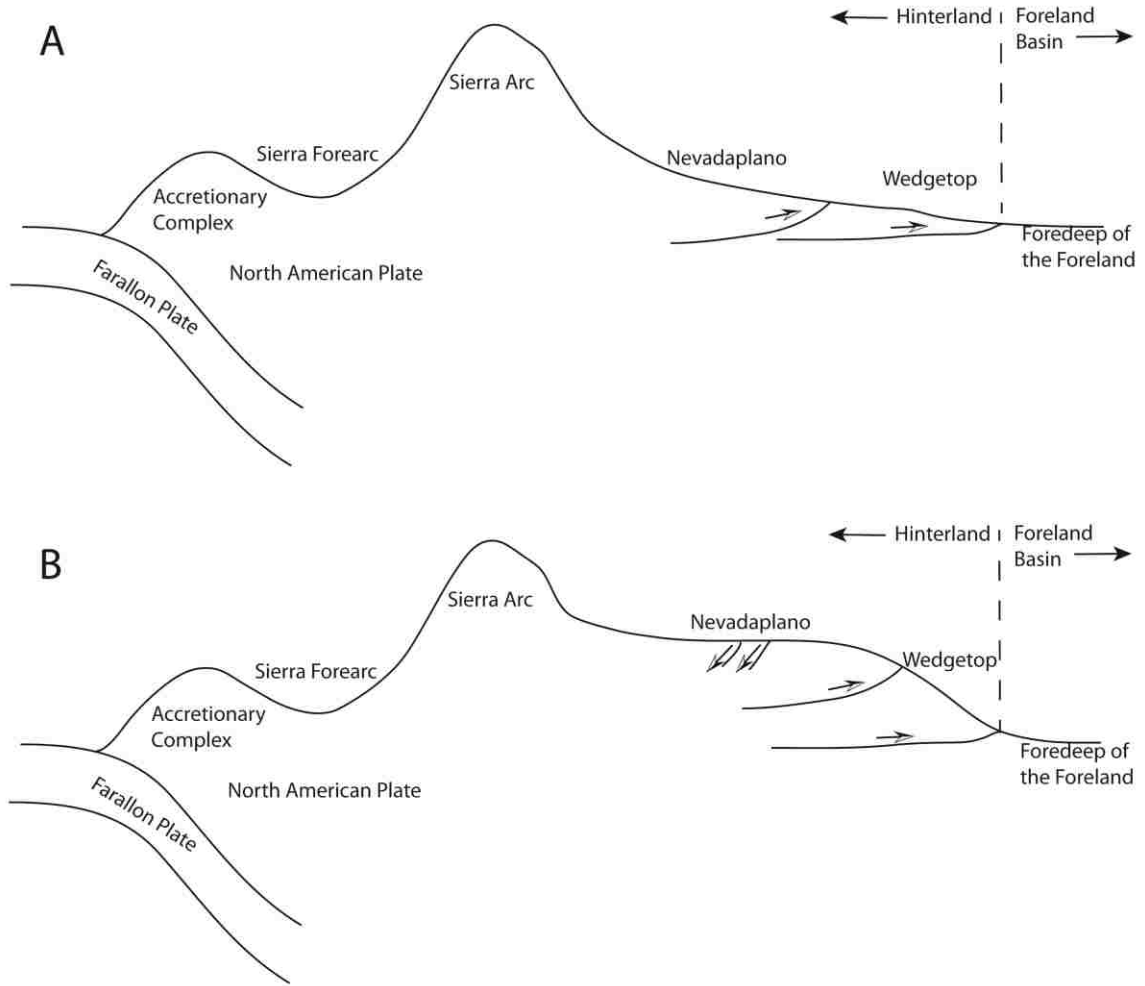
Figure 1.3. A very generalized cross section of North America during the Sevier Orogeny, depicting the tectonic settings of the formations discussed in the text (after DeCelles, 2004). A) represents a hypothetical configuration supporting the null hypothesis, in which the hinterland and the foreland are nearly the same elevation. B) represents a hypothetical configuration where the alternative hypothesis where deposits of the hinterland and the foreland would be at drastically different elevations.

CHAPTER 2

VOLCANICLASTIC PRESERVATION OF A MID-CRETACEOUS (CENOMANIAN)

FLORA IN THE WILLOW TANK FORMATION OF SOUTHERN NEVADA

Introduction

The Cretaceous was a very significant interval in the evolution of global floras. It
was not until the Aptian (125-112 Ma) that Angiospermophyta, the flowering plants,
became widespread, adding a major new component to terrestrial ecosystems (Lupia et
al., 1999; Feild and Arens, 2005). This significant evolutionary event is preserved in
many regions around the globe. Here I report a new occurrence of a mid-Cretaceous
(Cenomanian) flora from southern Nevada, which was positioned at the very front of the
Sevier fold and thrust belt (Schmitt and Kohout, 1986; Schmitt and Aschoff, 2003; Bonde
et al., 2008). This flora, located close to the Sevier plateau, provides insight into an
ecosystem separate from more coastal contemporary floras in Utah, Wyoming, and
Montana. If the flora of the Willow Tank Formation are similar to these more coastal
floras, then the flora would support a low "coastal" elevation. If the Willow Tank
Formation flora are dissimilar from the coastal floras, then that would support a different
paleogeographic setting.

Geologic Setting

Deposits which contain the fossil assemblage lie within the Willow Tank
Formation. This formation represents deposits of a seasonally arid, fluvial system which
drained the Sevier highlands to the west (Reese, 1989; Bonde et al., 2008). The

interpretation of a seasonally arid environment is supported by the presence of abundant

carbonate nodule horizons I interpret to be calcisols (cf. Mack et al., 1993). The Willow

Tank Formation is up to 150 m thick in places and is divided into two informal members,

a basal conglomerate and an overlying "mudrock" unit (Figure 2.1) (Carpenter, 1989).

This formation was deposited in the foredeep of the Sevier retroarc foreland basin

(Figure 1.2) (Schmitt and Kohout, 1986; Schmitt and Aschoff, 2003). Recent ^{40}Ar/^{39}Ar

dates of volcanic ash beds place the upper member within the Cenomanian (Pape et al.,

2011). Although not observed in this study, Ash and Read (1976) report the presence of

the tree fern *Tempskya,* which also supports a mid-Cretaceous age for the Willow Tank

Formation as this taxon is only known from the Aptian to the Cenomanian of North

America (Tidwell and Hebbert, 1992). The upper mudrock member consists of thin- to

medium-bedded gray claystone and sandstone (Carpenter, 1989). Approximately 15% of

this member consists of volcaniclastic sediments, with the remainder being siliciclastic

(Bonde, 2008). Deposits of this upper member are interpreted to represent a

multichannel, aggradational fluvial system with abundant volcaniclastic input (Bonde

2008). This interpretation is based upon the deposits of the Willow Tank Formation being

consistent with Makaske's (2001) model for anastomosed fluvial systems. The upper

member of the Willow Tank Formation has single-storied channel sandstones, which are

in sharp contact with overbank mudrocks, there is an abundance of overbank fine

deposits, there are common crevasse splay deposits, and avulsion deposits, and some

evidence for overbank ponding; the final criterion of Makaske's (2001) is the presence of

ribbon sandstone bodies, which cannot be determined in exposures in Valley of Fire due

to the cross-sectional nature of the outcrop (Bonde, 2008).
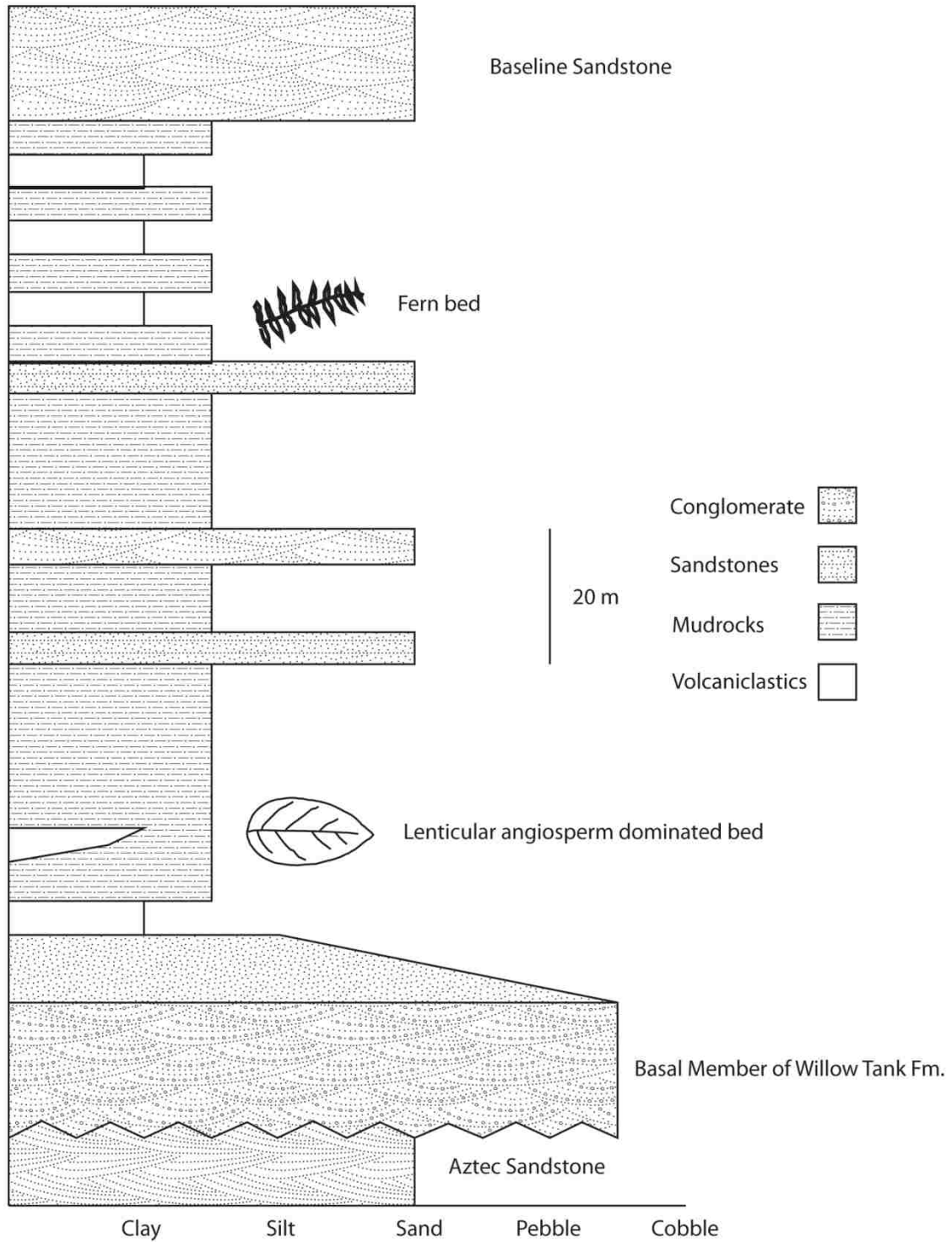
Figure 2.1. Diagramatic stratigraphic section of the Willow Tank Formation. Leaves denote horizons which have produced plant fossils. There is a slight angular unconformity between the Aztec and Willow Tank. The contact with the Baseline Sandstone is interbedded.

Location and Methods

In this study I focused on exposures of the Willow Tank Formation in the North Muddy Mountains (Figure 1.1), within Valley of Fire State Park, Clark County, Nevada. Precise coordinates of collection sites may be obtained upon request at the curatorial repository, the Nevada State Museum-Las Vegas.

Collection.—Fossil-bearing localities were identified by prospecting exposures of the Willow Tank Formation and revisiting known sites from previous studies. Once a fossil-bearing locality was discovered the location was noted using GPS.

After a site was identified, any specimens found on the surface as float, or any specimens that were in danger of being destroyed by the elements, were collected. Highly fossiliferous sites were left alone, and a crew was later brought back to properly extract the specimens. In the lab, broken specimens were glued back together with cyanoacrylate glue. As necessary, matrix was removed with a dental pick or Dremmel tool.

To excavate the second plant site, a meter floating grid (after Organ et al., 2003) was placed on the surface of the volcaniclastic unit of interest, aligned to strike and roughly parallel to dip. Volunteers then set to digging down to the plant bearing horizon at the base of the unit. Samples collected from the first volcaniclastic plant site were gathered from surface collection as noted above and by digging into the unit to recover specimens. No attempt was made to quarry this site as it is found on a steep exposure.

Identification.—I compared the leaf impressions to published figures and descriptions of other plant specimens. Description of angiosperm leaves follow Hickey's (1973) morphological terminology. Resources used for comparison include Hickey and Doyle

(1977), Dilcher and Crane (1984), Crabtree (1987), Dilcher and Basson (1990), Tidwell (1998), Spicer and Herman (2001), Deng (2002), Peppe et al. (2007), and Peppe et al. (2008).

Site Geology.—I described and interpreted the sedimentology of each fossil-bearing horizon and placed it into a stratigraphic context. This was done by identifying the lithology of the fossil bearing horizons in addition to sedimentary structures or lack of structure within the unit. As the focus of this study is on volcaniclastic units, the bounding beds were also described based upon lithology and sedimentary structures. Once the lithology and sedimentary structures were identified, the geometry of the bed was described. This information was then used to make an interpretation as to the depositional environment of the fossil bearing horizon. Once the sedimentology was resolved the unit was place within the stratigraphic framework of Bonde (2008).

Curation.--Upon completion of the study, all specimens will be reposited at the Nevada State Museum and Historical Society, Las Vegas (abbreviated VM).

<div align="center">Systematic Paleontology</div>

This study identifies 5 taxa present within exposures of the Willow Tank Formation. There is one sphenophyte, two filicophytes, and two angiosperms. Description and diagnoses of taxa are included below.

<div align="center">Division SPHENOPHYTA (Horse-tails)</div>

<div align="center">EQUISETALES</div>

<div align="center">Genus *Equisetites* Sternberg 1883</div>

<div align="center">*Equisetites* sp.</div>

Description.— Numerous specimens of stalk-like body fossils are preserved in the second preservational site of the Willow Tank Formation. These stalk-like fossils are nodal; most are single stalked, although some stalks are branched. Stalks range in width from 4-32 mm. Internodal length is highly variable. Occasionally single leaves are preserved. These specimens are assigned to the extinct Equisetale *Equisetites* (Figure 2.2A), which is defined as fossil Equisetales which cannot be positively assigned to the modern genus *Equisetum* (Watson and Batten, 1990).

Division FILICOPHYTA (Ferns)

OSMUNDACEAE

Genus *Cladophlebis* Brongniart 1849

Cladophlebis sp.

Description.—Specimens referred to the genus *Cladophlebis* have a rachis measuring at least 55 mm long with fully attached pinnae. The longest of the pinnae is 24 mm; the pinnae become increasingly shorter toward the distal end of the rachis. The pinnae have an undulating texture composed of secondary pinnae, which are up to 1 mm in amplitude (Figure 2.3).

MATONIACEAE

Genus cf. *Matonia* Brown 1829

cf. *Matonia*

Description.—Specimens referred to *Matonia* consist of a rachis with pinnae. The longest specimen, which is not complete, is 42 mm. The pinnae of this taxon are roughly the same length, 24 mm, from proximal to distal end of the rachis. Pinnae are completely attached to the rachis (Figure 2.4).

Division ANGIOSPERMOPHYTA (Flowering plants)

Class DICOTYLEDONAE

MAGNOLIACEAE

Genus *Magnolia* L.

Magnolia sp.

Description.—Specimens attributed to the genus *Magnolia* consist of simple, obovate

leaves, with an acute apex and entire margin. Venation is eucamptodromous, consisting

of a well-defined primary vein with curving, unintercepting secondaries which alternately

diverge from the primary (Figures 2.2B & 2.5).

INDETERMINATE FAMILY

Genus *Sapindopsis* Fontaine 1889

Sapindopsis magnifolia Fontaine 1889

Description.—Leaves attributed to *Sapindopsis magnifolia* are odd-pinnately compound.

Leaflets have an entire margin, are eucamptodromus in venation, and are oblong in shape.

Both the apex and base of leaflets are acute in morphology. Secondary veins are opposite

and parallel to their terminations (Figure 2.2C).
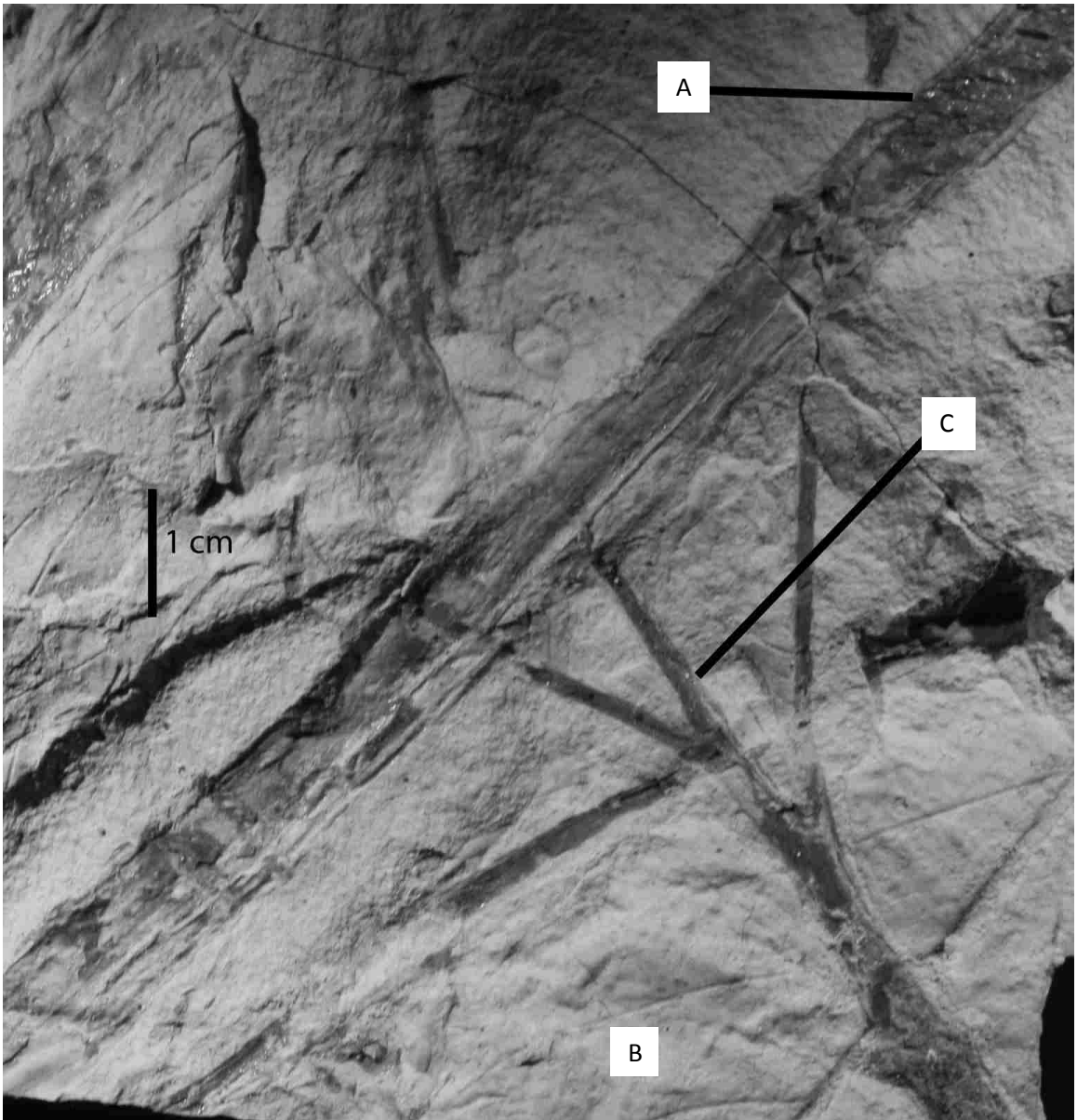
Figure 2.2. A) Stalk of *Equisetites*; B) *Magnolia* leaf; C) petiole of *Sapindopsis* (previously figured in Bonde et al., 2010).
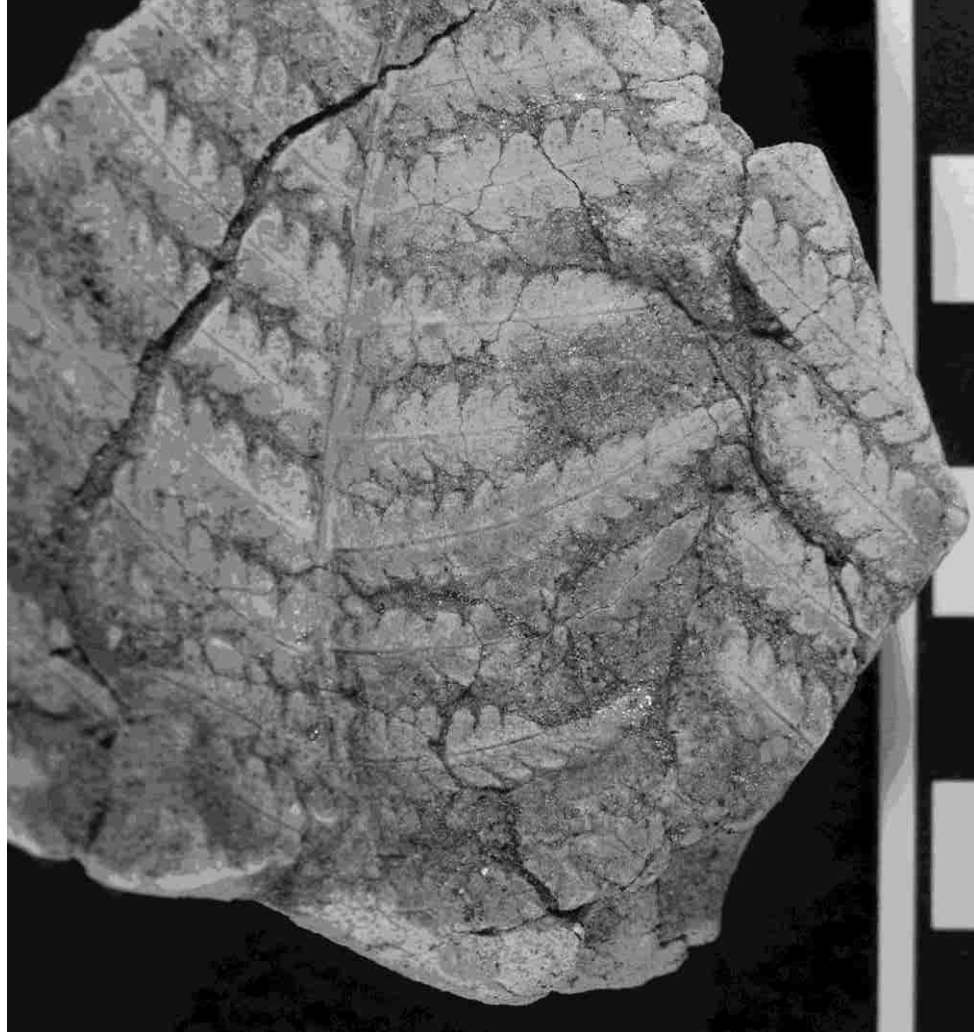
Figure 2.3. *Cladophlebis* sp. Scale bar to right is in centimeters (previously figured in Bonde et al., 2010).
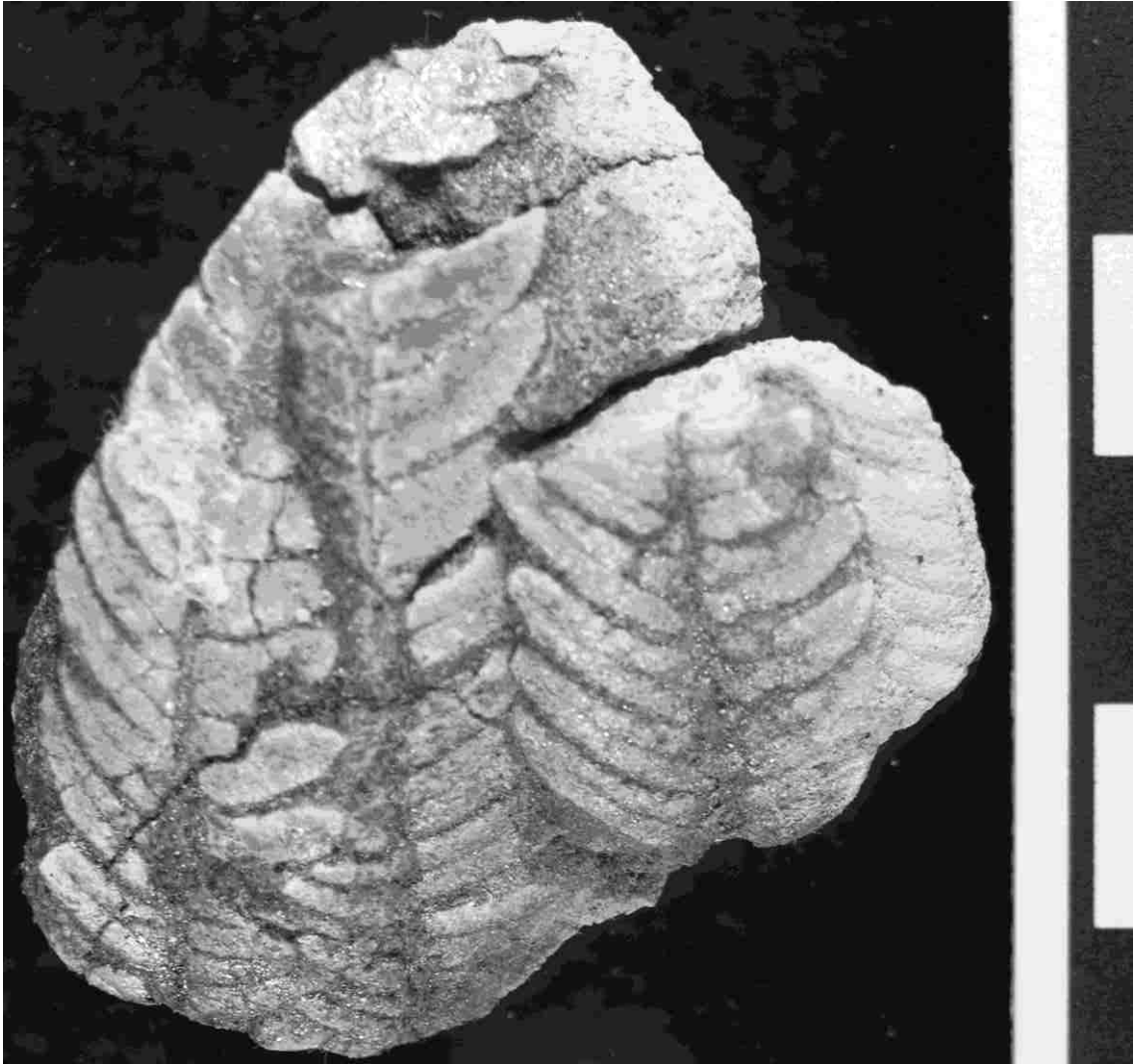
Figure 2.4. cf. *Matonia* (previously figured in Bonde et al., 2010), scale bar at the right is in centimeter intervals.
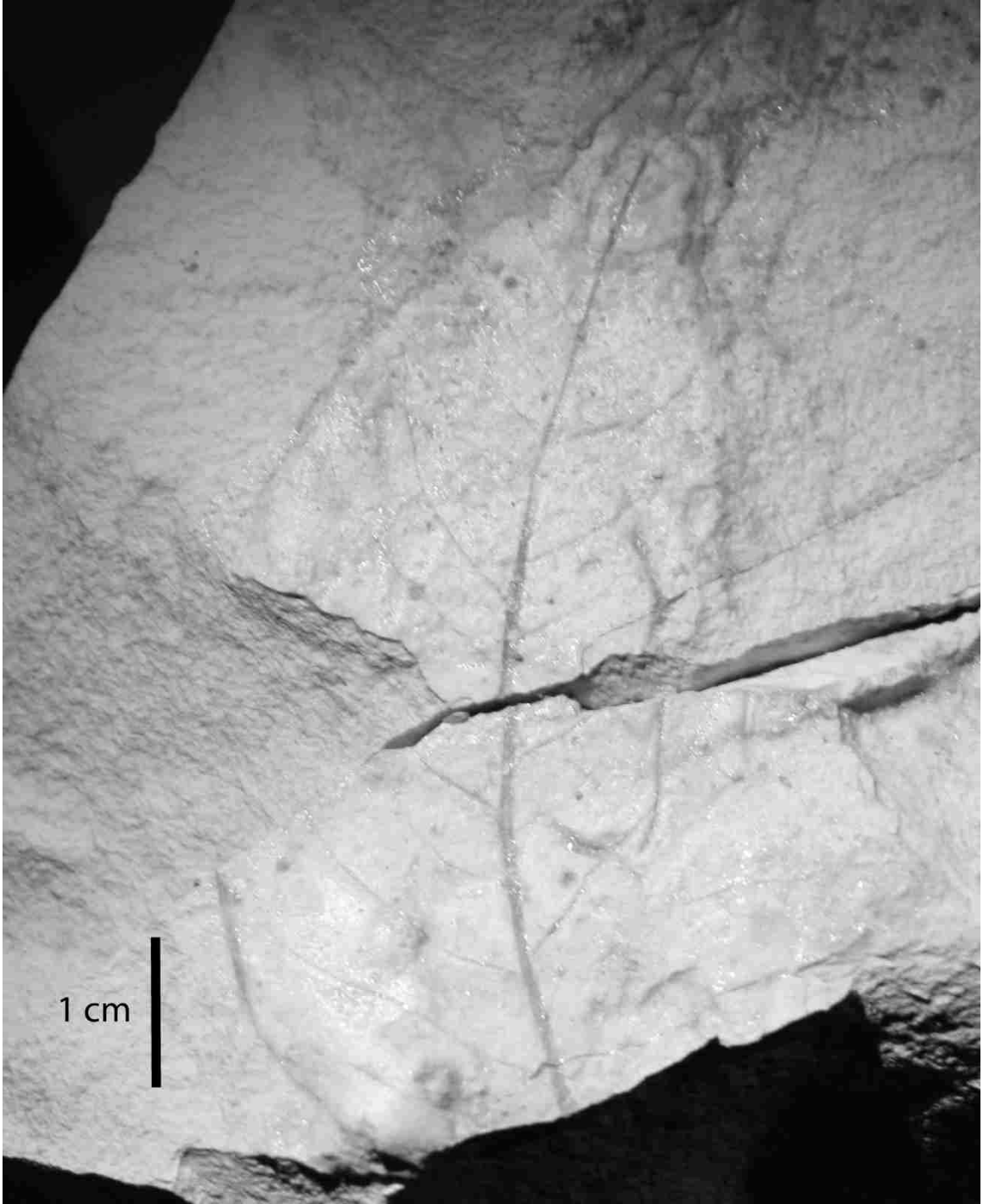
Figure 2.5. *Magnolia* sp. (previously figured in Bonde et al., 2010)

Taphonomy

Plant fossils in the Willow Tank Formation are preserved in two taphonomic modes. The first mode consists of plant body fossils distributed in a tabular, massively bedded, volcaniclastic unit near the top of the formation (Figure 2.1). The second mode is plant macrofossils preserved in a lenticular, planar-laminated, volcaniclastic unit near the base of the formation (Figure 2.1). To date, no plant macrofossils have been discovered in any of the siliciclastic units of the Willow Tank Formation.

The first preservational mode is dominated by ferns (*Cladophlebis* and cf. *Matonia*); no angiosperms were observed in the massively bedded unit. This tabular unit is traceable for roughly 50-60 m and is 2-3 m thick. This volcaniclastic unit is bounded on top and bottom by tabular massive mudrocks (Figure 2.1). The upper mudrock is mottled red-green and contains abundant carbonate nodules. Plant fossils are not found along bedding planes but are found three dimensionally throughout the unit. Although no complete organism has been recovered, large portions have been successfully collected.

The second preservational mode is dominated by angiosperms and sphenophytes, with no ferns present. All plant macrofossils, with one exception, are found along a single bedding plane at the base of the volcaniclastic sediment (Figure 2.6). The one exception is a large branch or trunk of unknown affinity lying perpendicular to the strike of the bed, roughly 25 cm above the base of the unit (Figure 2.6). This "trunk" has a width of 16 cm and at least 60 cm of the specimen was exposed. It continues into the hill and has not been fully excavated due to problems of overburden removal.

Many stalks and leaves are preserved flat, however a number of leaves are preserved at or just above the base of the volcaniclastic unit and are found curled in three

dimensions as if folded over on themselves in a parabolic shape in cross-section. There is not an apparent difference in distribution of taxa across the base of this unit. This lenticular unit is roughly 20-30 m wide; and 2 m thick at its thickest point, tapering in both directions.

Some leaves from this unit have small (<2 mm diameter) spherical impressions within them of unknown origin. These occur on both the flat and curled specimens.

Figure 2.6. A) Image showing the basal plant bed in relation to the underlying mudrock. B) Image showing the relationship of the "trunk" to the plant bed.
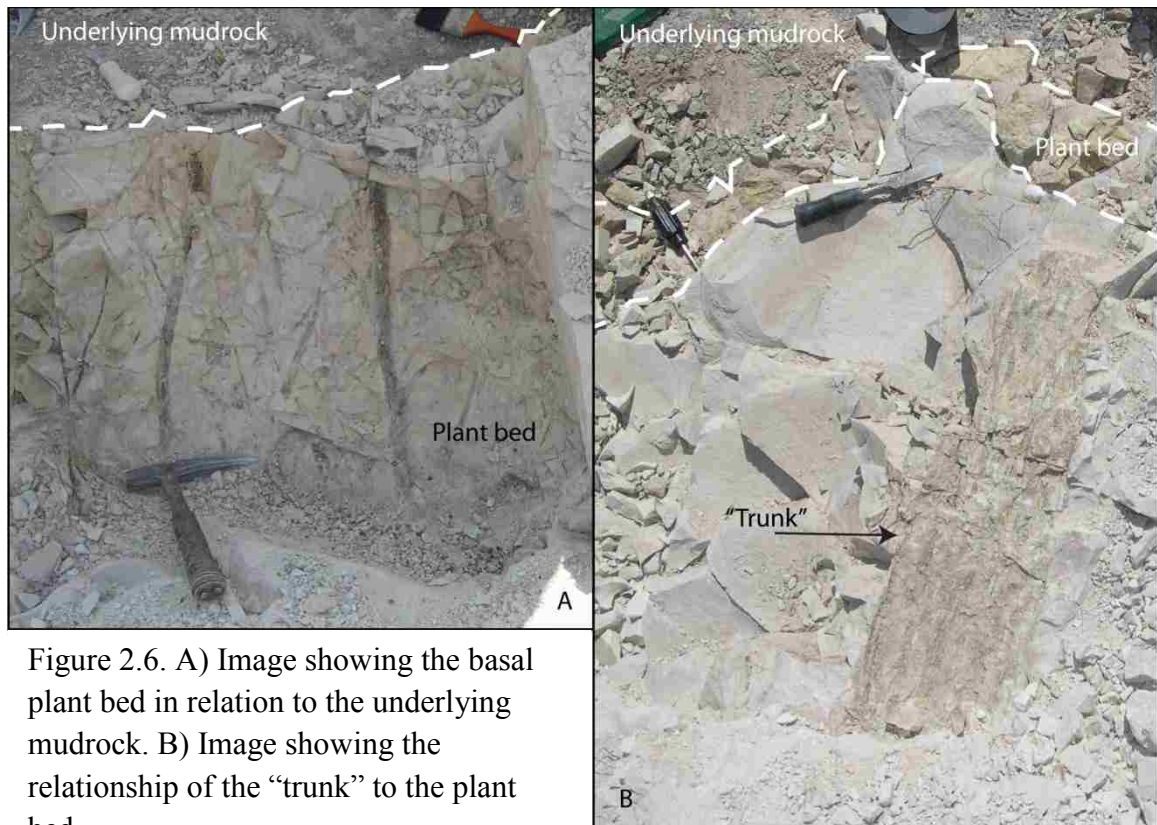
Discussion

Volcaniclastic sedimentation is ideal for preserving snapshots of prehistoric ecosystems as deposition typically ranges from the span of a day to a year (Behrensmeyer et al., 1992). The rate of deposition is a function of the rate that the volcaniclastic sediment is delivered and transported across a landscape. Modern volcanic events reliably preserve the regional autochthonous vegetation in the form of compressional and

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impressional remains of macroscopic organs (Burnham and Spicer, 1986). Both taphonomic modes identified in this study are volcaniclastic in nature but differ in the interpreted depositional environment. Burnham and Spicer (1986) observed the effects of a volcanic eruption in Chiapas, Mexico, in an area with a large amount of agricultural development, so the pre-eruptive vegetation was known. When they went back post-eruption they observed that ash-fall beds nicely preserved only the autochthonous vegetation and that allochthonous material was rare if present at all (Burnham and Spicer, 1986), showing the spatial fidelity of ash-fall beds.

The fern-dominated, first taphonomic mode of the Willow Tank Formation flora is interpreted to represent a dry, overbank setting. This is indicated by the tabular nature of the underlying and overlying massive, mottled, carbonate-bearing mudrock units. The beds are interpreted as overbank fines with pedogenic development in a seasonally arid, well-drained floodplain (Bonde et al., 2008). In this taphonomic mode ferns are the only preserved plant. It is not uncommon in modern volcanic settings to find ferns as the most common plant in volcanically-disturbed regions. Ferns are easily dispersed by long-or short-range transport of spores, in addition to their ability to vegetatively expand from rhizomes (Spicer et al., 1985; Walker and Sharpe, 2010). Once established, ferns can create dense stands which may inhibit other vascular plants from colonizing a disturbed area (Walker and Sharpe, 2010). These sorts of fern-dominated, volcanic ash flats have been reported from other regions of North America during the Cretaceous (Crabtree, 1983). Thus I interpret the first taphonomic mode to represent early successional ferns established on a well-drained floodplain subject to episodic volcaniclastic input.

The second taphonomic mode I interpret to represent a paludal setting. The lenticular nature of the volcaniclastic unit, with horizontal laminae and underlying fine-grained, laminated mudrock with no pedogenic development is consistent with a pond setting. This taphonomic mode, unlike the first, is dominated by angiosperms rather than ferns. In this taphonomic mode abscised leaves are the most common structure preserved. In modern volcanic settings volcaniclastic input has been found to initially bury pre-existing leaf litter. Subsequent volcaniclastic input can cause abscission of leaves still on the twig (Burnham and Spicer, 1986). Modern studies of leaf assemblages have shown that leaves rarely fall farther from their source than the original plant is tall; therefore, leaves rarely fall more than 50 m from their source (Ferguson, 1985). Elongate plant remains, such as *Equisetites* stalks and twigs, were not preferentially aligned so there is no indication of a current or perhaps an eruption direction. Early angiosperms, especially *Sapindopsis*, were predominantly herbaceous and weedy, and they were most common along water ways during the mid-Cretaceous (Hickey and Doyle, 1977; Wing and Boucher, 1998).

The presence of *Sapindopsis magnifolia* indicates that the Willow Tank Formation flora is most similar to Potomac Flora Zone IIB of Hickey and Doyle (1977), interpreted to be Albian to earliest Cenomanian in age. By the Cenomanian, Crabtree (1987) observed that a north-south provinciality had developed between the northern and southern Rocky Mountains. The flora of the Willow Tank Formation is not complete or diverse enough to say whether southern Nevada's flora has affinities with one or the other of these provinces, or whether it represents a separate botanical province. That said, the Willow Tank Formation flora is superficially similar to the uppermost plant bearing

levels of the Albian Aspen Shale flora of western Wyoming with the co-occurrence of the fern *Cladophlebis* and the angiosperm *Sapindopsis magnifolia* (Peppe et al., 2008). The one major difference between all of the Rocky Mountain floras and the southern Nevada flora is the presence of *Magnolia* in southern Nevada compared to the former locales. It is not known whether this difference is due to paleoecological differences or to taphonomic biases. Another difference between the Rocky Mountain floras and the southern Nevada flora is that there are no toothed-margin leaves present in southern Nevada. This may reflect paleoclimatic differences between the two regions, but more specimens would need to be recovered from southern Nevada for a proper comparison. A higher proportion of angiosperm taxa with toothed-margins versus entire margins is a reliable proxy for cooler versus warmer temperatures (Royer et al., 2009 and references therein). Royer et al. (2008) show that there can be intraspecific variation in leaf margin morphology related directly to mean annual temperature, with colder areas having more teeth than members of the same species in warmer regions. This could point toward the Willow Tank flora representing a warmer climate than the contemporaneous Rocky Mountain flora based upon the morphology of *Sapindopsis* leaves between the two regions.

The flora of the Willow Tank Formation provides an interesting, preliminary comparison to better known floras of the Rocky Mountain region and New England. In the future the Cretaceous flora of the southwest will become more robust with further sampling and provide more insightful comparisons. In the meantime, the southern Nevada flora can be said to be superficially similar to contemporaneous floras of other

parts of North America, with the one exception that no toothed-margin leaves have been found in Nevada.

Conclusion

The taphonomic modes of the volcaniclastic, plant-bearing horizons within the Willow Tank Formation are consistent with an autochthonous floristic assemblage preserved in what is interpreted to be the foredeep of the Sevier foreland basin during the Cenomanian. Taxonomically, the Willow Tank Formation flora is similar to other more coastal floras from the Rocky Mountain region. These similarities suggest a similar elevation of deposition. The differences between the Rocky Mountain flora's and the Willow Tank Formation flora imply that southern Nevada was warmer than the Rocky Mountain region during the mid-Cretaceous, however more material needs to be recovered from Nevada for a more rigorous comparison. Floral remains from the Rocky Mountain region are found in not only volcaniclastic settings, but also in other clastic settings. Thus a preservational bias between these different depositional settings may also be at play. This study does not invalidate either the null hypothesis or my alternative hypothesis.

CHAPTER 3

TWO NEW CRETACEOUS (BARREMIAN?-APTIAN) VERTEBRATE

OCCURRENCES FROM CENTRAL NEVADA

Introduction

Vertebrate fossils have long been known from the Lower Cretaceous Newark
Canyon Formation of central and eastern Nevada (David, 1941; Smith and Ketner, 1976).
Here I describe two new occurrences of vertebrate remains from the Newark Canyon
Formation from central Nevada. Previous vertebrate finds have been confined to the
Diamond Range of central Nevada (David, 1941); this study expands vertebrate-bearing
locales to the Pancake and Fish Creek Ranges (Figure 1.1). These vertebrate faunas will
be compared to the roughly contemporaneous Ruby Ranch Member of the Cedar
Mountain Formation. If preservational modes differ, or if geographically sensitive taxa
are different between the two units then this supports that the Newark Canyon Formation
and the Cedar Mountain Formation were deposited in different paleogeographic settings.
If perservational modes are similar and geographically sensitive taxa are similar, then the
Newark Canyon Formation and the Cedar Mountain Formation likely were deposited
under similar environmental conditions.

Geologic Setting

The Newark Canyon Formation represents lacustrine and fluvial deposits of a
wedge top, piggy-back basin (Figure 1.2) (Vandervoort and Schmitt, 1990; Druschke et
al., 2011). This formation was first named by Nolan et al. (1956) for post-Paleozoic
sedimentary rocks which underlie Paleogene volcanic rocks in the Diamond Range of
central Nevada. Biostratigraphy of plant, invertebrate, and vertebrate remains were used

to designate the unit as Lower Cretaceous (MacNeil, 1939; David, 1941; Fouch et al., 1979). Druschke et al. (2011) subsequently used U/Pb dates of detrital and primary zircons to confirm an Early Cretaceous (Barremian?-Aptian) age. With a 116.1 ±1.6 Ma U/Pb date on primary zircons from a waterlain tuff, Drushcke et al. (2011) were able to establish that the upper portion of the Newark Canyon Formation in the type section in the Diamond Range was Aptian in age. Units within the Diamond Range have been lithostratigraphically correlated southward to exposures in the Fish Creek Range (Vandervoort, 1987), one of the areas of interest in this study. This makes the Newark Canyon Formation in the Diamond and Fish Creek Ranges roughly temporally correlative to the lower Ruby Ranch Member of the Cedar Mountain Formation from the Sevier Foreland of Utah (Kirkland et al., 1999). Vandervoort (1987) and Vandervoort and Schmitt (1990) interpreted deposits of the Newark Canyon Formation as being proximal to highlands of the Sevier retroarc hinterland, yet west of the Sevier fold and thrust front. The basal portion of the formation is interpreted to represent a period of time when through-flowing river systems drained the Nevadaplano highlands to the west out into the Sevier foreland (Vandervoort, 1987; Vandervoort and Schmitt, 1990). Later the Newark Canyon basin transitioned into a lacustrine basin (Vandervoort, 1987; Vandervoort and Schmitt, 1990), in which the oldest lacutrine units in the Great Basin were deposited (Fouch et al., 1979).

Background

Previous paleontological studies of the Newark Canyon Formation are primarily descriptive and biostratigraphic in scope. MacNeil (1939) described the mollusk fauna, with a note about the macroflora, concluding that the formation is Cretaceous in age.

David (1941) described a new teleost fish, *Leptolepis nevadensis*, in a genus known from the Jurassic through the Cretaceous. Smith and Ketner (1976) were the first workers to recognize the presence of terrestrial vertebrates in the Newark Canyon Formation. In a study focused on mapping and stratigraphy of the area around Eureka, Nevada, for economic purposes, they noted the occurrence of indeterminate crocodilian teeth fragments, possible ankylosaur tooth fragments, and one "coelurid" dinosaur tooth (Smith and Ketner, 1976). This was the first mention of Cretaceous terrestrial vertebrates in the state of Nevada. Subsequently numerous researchers have combed exposures of the Newark Canyon Formation without much success. Clemens et al. (1979) reported the recovery of two multituberculate mammal teeth from an abandoned ant hill near Eureka, Nevada, but these teeth were unidentifiable to genus level, and no additional information was provided. An additional unidentifiable bone fragment was reported by Vandervoort and Schmitt (1990), which was the last mention of vertebrate material in the Newark Canyon Formation until this study.

Beginning in 2008 a multi-institutional research group has focused on the study of the paleoecology of sedimentary units of east-central Nevada. As part of this group, I have extensively prospected exposures of the Newark Canyon Formation in the Pancake and Fish Creek Ranges. The fossils reported here greatly expand the known distribution and diversity of Cretaceous vertebrates from the Newark Canyon Formation.

Location and Methods

The foci of this study are exposures of the Newark Canyon Formation which crop out in the Fish Creek and Pancake Ranges of east-central Nevada (Figure 1.1). Specific fossil bearing locations are identified by scouring previously mapped and unmapped

exposures of the unit. Specific locations are recorded with a hand held GPS unit and coordinates are noted and reposited at the final specimen repository, the Sierra College Natural History Museum, in Rocklin, California.

Institutional Abbreviations

SCNHM--Sierra College Natural History Museum, Rocklin, CA

Prospecting

As most of the units under examination in this study have never been or have not been prospected in decades I set to systematically scouring aerial exposure of the Newark Canyon Formation. With the aid of a crew, ranging from 3-5, we conducted north-south transects or east-west transects, depending on the nature of exposure, of surficial exposures of the unit. Fossil localities were documented as noted above.

Collection

All material was recovered as surficial float with the exception of one excavation. The recovery of float entails documentation of the fossil site, and whether or not the material is *in situ* or is allochthonous. If a site is found, the nearby surroundings are closely examined to see if any materials are within a "fingers" depth in the highly weathered matrix. In sandstones most material is visible on the surface without doing the "fingers" depth approach.

The single excavation which was conducted utilized the Organ et al. (2003) floating meter grid system. A meter grid was laid out over the exposure, utilizing non-invasive means (no nails) and a floating pvc pipe grid. All materials recovered were mapped to within a centimeter.

Taphonomy

Due to careful transect oriented prospecting, stratigraphic units were well known while prospecting. Therefore, when a fossil site was identified it was immediately noted which stratigraphic interval from which it came. More specifically, sedimentological data was obtained, such as grain size and sedimentary structures of fossil bearing horizons. Poor lateral exposure made determining geometry difficult with the exception of the most resilient beds (channel sandstones). All characteristics mentioned in the taphonomy section of Chapter 1 were summarized for each fossil site in the field and in the lab.

Identification

Fossil material was identified using published reference material (Hay, 1908; Maisey, 1978; Kirkland et al., 1998; Cifelli et al., 1999; Kirkland et al., 1999; Weishampel et al., 2004) and using personal experience from working in other mid-Cretaceous units in Montana, Wyoming, Idaho, Utah, and Nevada.

Systematic Paleontology

CHONDRICHTHYES Huxley, 1880

HYBODONTIDAE Owen, 1846

Diagnosis- Hybodontidae is represented by a single dorsal fin spine (Figure 3.1). The very distal tip of the spine is missing. The length of the preserved portion is 2.7 cm with a diameter of 0.5 cm. This spine has 5 visible longitudinal ridges running the entire length of the preserved portion. There is a slight dorsal curve in the specimen, however due to shortness of the spine the degree of curve cannot be determined.

Discussion- The longitudinal ridges and hollow base of this specimen are consistent with identification as a hybodont dorsal-fin spine (Maisey, 1978). The other diagnostic

characteristics of a hybodont fin spine are denticles on the posterior side of the element

(Maisey, 1978), in this case the posterior side is obscured by matrix and the vertebra of

an archosaur. Preparation was halted out of concern for the fragile nature of the

specimen. This element was found in a granule-to-pebble-rich, coarse sandstone. The

high energy needed to transport these coarse grains likely led to the fragmentary nature of

the element and possible abrasion of denticles. Hybodontidae is a group known to

inhabit marine, brackish, and freshwater environments (Maisey, 1978). Hybodont shark

remains are known from the roughly contemporaneous Cedar Mountain Formation of

Utah, a unit interpreted to have been deposited in fluvial-channel and overbank settings

(Kirkland et al., 1999).
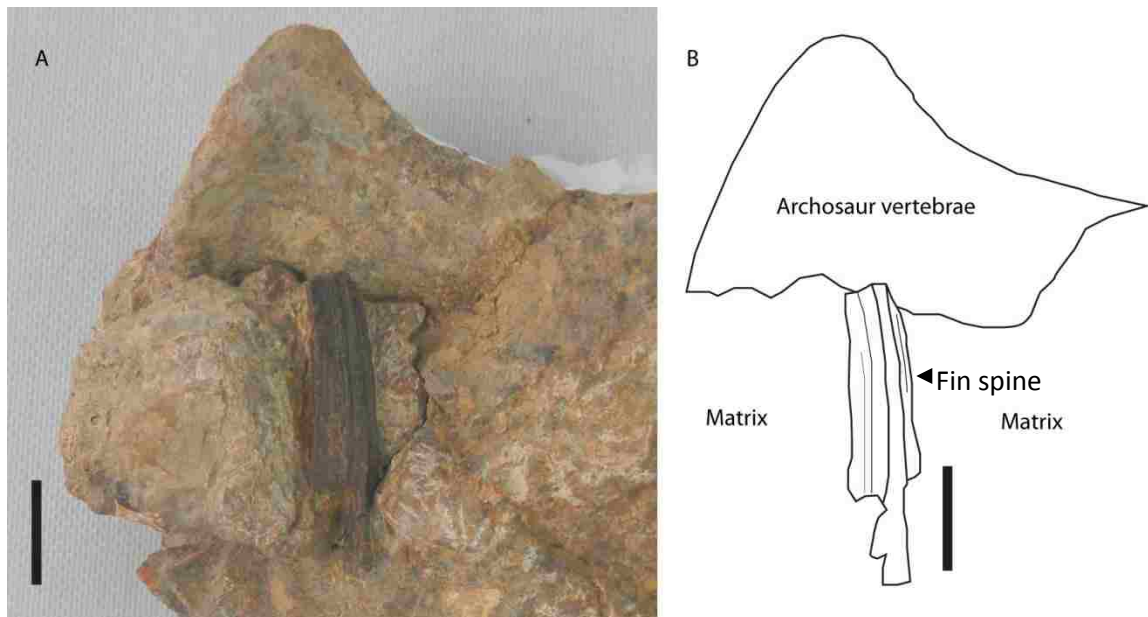
Figure 3.1. A) Hybodont shark spine resting against an archosaurian vertebra (SCNHM VRD 208). Note the coarse nature of the matrix. B) Line drawing of A, highlighting the longitudinal ridges on the spine and more clearly delineating the vertebra. Scale is 1 cm in both images.

REPTILIA

TESTUDINES Linnaeus, 1758

GLYPTOPSIDAE Marsh, 1890

GLYPTOPS SP. Marsh, 1890

Diagnosis- A portion of a turtle carapace, isolated shell elements and appendicular elements are attributed to the genus *Glyptops* (Figure 3.2). The shell material has a serpentine, ridge-like ornamentation, which is diagnostic of this genus (Marsh, 1890; Hay, 1908). An isolated neural has the diagnostic hexagonal shape (Hay, 1908), with one broad end which would be anterior in this genus.

Discussion- *Glyptops* is the only identifiable turtle taxon from the Newark Canyon Formation. Material is known from numerous localities in varying degrees of preservation. In some instances material is found only as isolated fragments, and in others elements are articulated or associated. The most complete carapace of *Glyptops* is a 12 cm by 9 cm portion (Figure 3.2A). Also recovered have been two non-shell elements, two partial, unassociated tibiae.
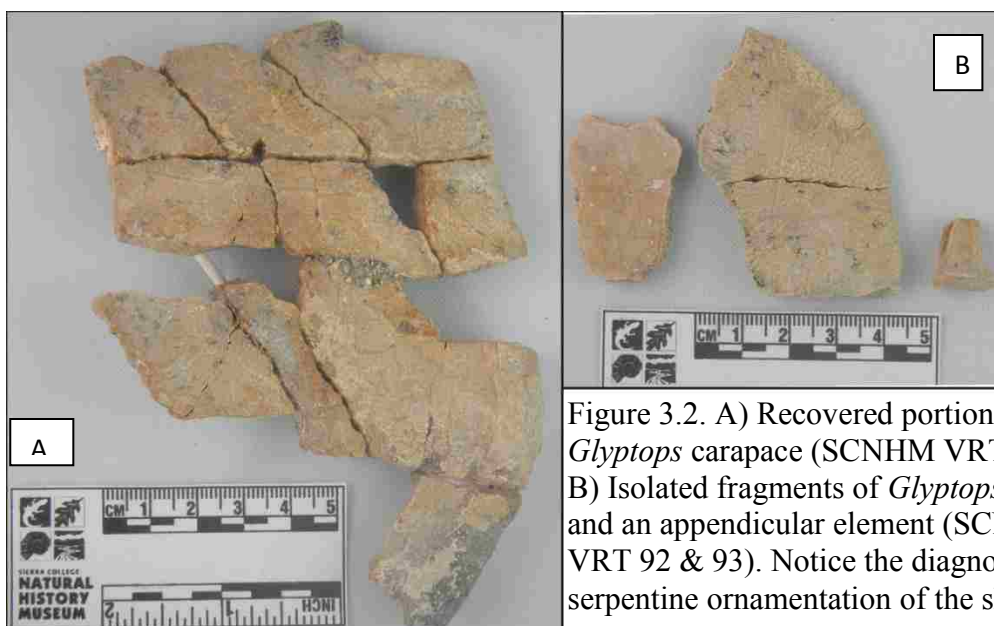
Figure 3.2. A) Recovered portion of a *Glyptops* carapace (SCNHM VRT 89). B) Isolated fragments of *Glyptops* shell and an appendicular element (SCNHM VRT 92 & 93). Notice the diagnostic serpentine ornamentation of the shell.

CROCODILIA Owen, 1842

CF. GONIOPHOLIDIDAE Cope, 1875

Diagnosis- Numerous crocodilian osteoderms and teeth have been recovered from the
Newark Canyon Formation (Figure 3.3). No complete osteoderm has been found, but the
portions recovered have an irregular, deep sculpturing. Many of the pieces show well-
developed annuli. Two crocodilian teeth have been found, one is a nearly complete
tooth, conical in shape with a broken tip. The tooth is 12 mm long and possesses parallel
carinae along its length (Figure 3.3 B). The other is similar to the first but is complete and
possesses a rounded, blunt tip (Figure 3.3 C).

Discussion- Although no family- or genus-level diagnostic material has been found, the
ornamentation on the portions of recovered osteoderms are most similar to those of
goniopholid crocodilians, the irregular deep sculpturing in particular.

Figure 3.3. A) Crocodilian scutes showing the deep sculpturing which is typical of goniopholids but not diagnostic (SCNHM VRC 56). B & C are well-preserved crocodilian teeth (SCNHM VRC 55 & 56).

DINOSAURIA Owen, 1842

ORNITHISCHIA Seely, 1888

CF. THYREOPHORA Nopsca, 1915

Diagnosis- A number of elements of thick, blocky structure are attributed to thyreophoran

dinosaurs (Figure 3.4). No absolutely diagnostic elements have been found in this study.

Unpublished teeth in the University of California Museum of Paleontology collections

collected from the Newark Canyon Fm by Don Lofgren are most definitely thyreophoran,

as identified by having a blade-like crown and basal keel, these being diagnostic features

of thyreophorans (Norman et al, 2004). Two dorsal ribs from the Pancake Range have a

very blocky cross-section and are most similar in morphology to those of thyreophorans;

these were found associated with some unidentified blocky articulated elements.
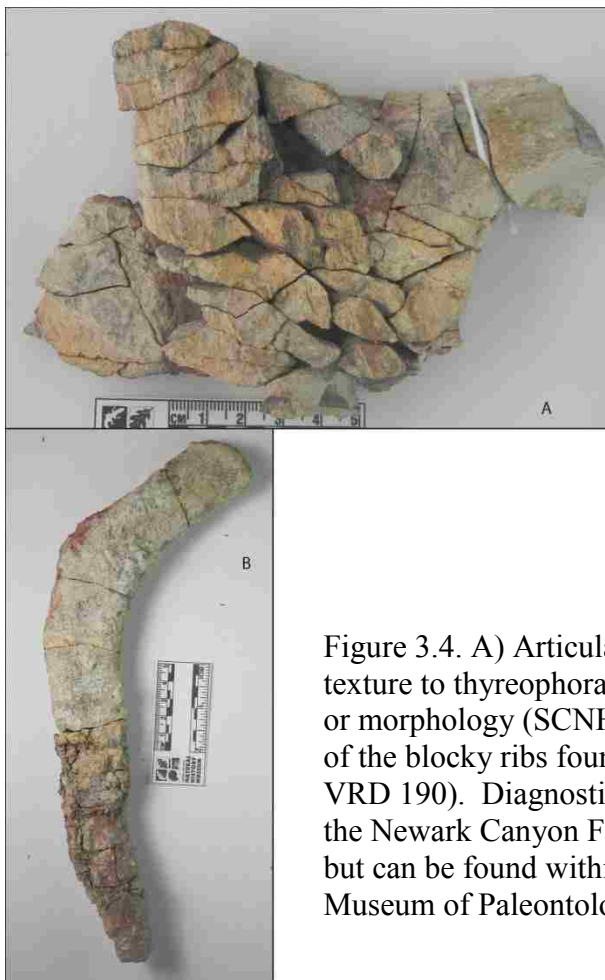
Figure 3.4. A) Articulated blocky bones with similar bone texture to thyreophorans, but without a diagnostic texture or morphology (SCNHM VRD 181). B) The head of one of the blocky ribs found in association with A (SCNHM VRD 190). Diagnostic thyreophoran teeth collected from the Newark Canyon Formation by Lofgren are not figured but can be found within the University of California Museum of Paleontology collections.

Diagnosis- A vertebra from a conglomerate bed in the Pancake Range (Figure 3.5) is attributed to the Ornithopoda on the basis of a relatively dish-shaped centrum with an associated portion of the neural arch. In the Fish Creek Range, an associated ungual and metapodial are attributed to Ornithopoda (Figure 3.6). The ungual in particular is "hoof" shaped, similar to that of ornithopods. None of these elements is confidently diagnostic, thus the conferred diagnosis.
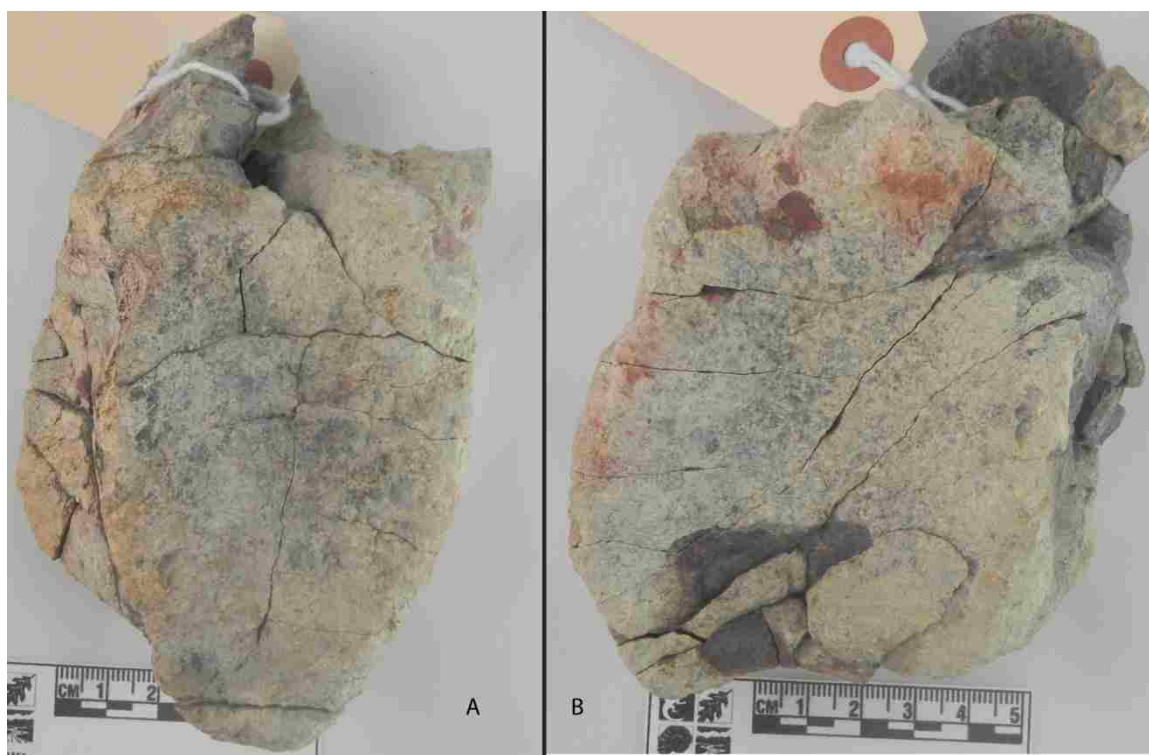
Figure 3.5. Image of the vertebra (SCNHM VRD 186) recovered from a pebble-cobble conglomerate in the Pancake Range. A) Cranial view. B) Lateral view. Note in A the right lateral plastic deformation of the centrum.
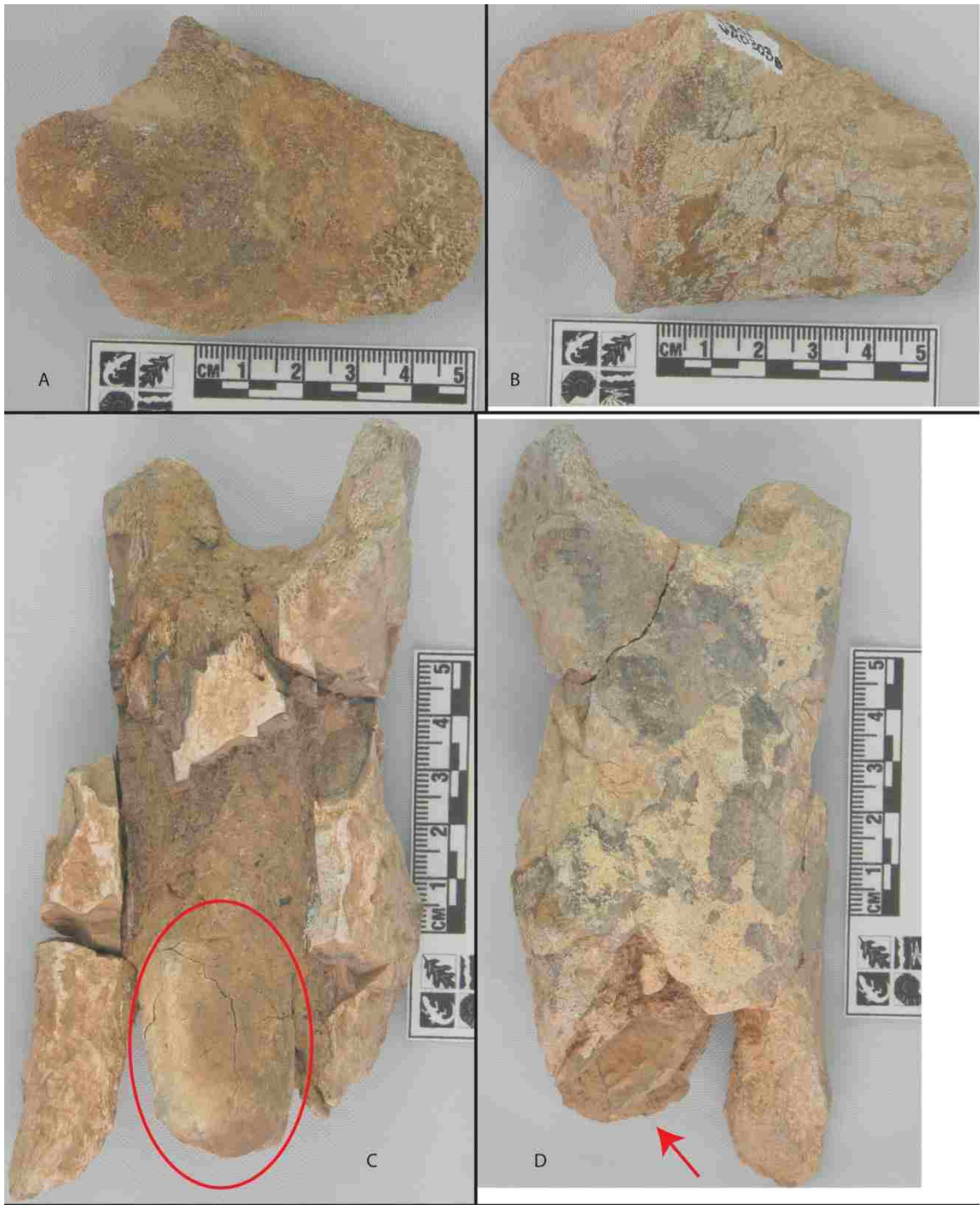
Figure 3.6. A&B) Ungual attributed to an ornithopod, showing differential weathering indicative of the element resting on a single side for several seasons. C&D) A metapodial associated with the above ungual, also attributed to an ornithopod, also showing differential weathering. The red oval on C and the red arrow on D denote a freshwater mussel which has grown on the element, a sign that the element was subjected to subaqueous conditions, in addition to subaerial weathering (SCNHM VRD 203).

SAURISCHIA Seely, 1888

THEROPODA Marsh, 1881

Diagnosis- The diagnosis of the presence of Theropoda within the Newark Canyon

Formation is based upon two teeth from the Pancake Range. One broken tooth is less

than a centimeter long and is tear-drop shaped in occlussal cross-section (Figure 3.7A).

This specimen has square-shaped denticles on the posterior side, while the anterior side is

relatively smooth and rounded. This tooth is visually similar to a dromaeosaur tooth but

is not diagnostic enough for such a designation. The second tooth is nearly complete,

missing the very tip, but poorly preserved (Figure 3.7B). It is roughly 3 cm long and

recurved. Poor preservation prevents description of the denticles of this specimen.

Discussion- The two teeth from the Pancake Range are the only diagnostic theropod

material from this study. Several skeletal elements from the Newark Canyon Fm in the

Fish Creek Range may also be from theropods but are not preserved well enough as to be

diagnostic.

Figure 3.7. A) Unweathered theropod tooth from the Pancake Range with well-preserved denticles on the posterior side (SCNHM VRD 195). B) Highly-weathered large theropod tooth from the Pancake Range (SCNHM VRD 194).

Table 3.1. Known vertebrates from the Newark Canyon Formation of east-central Nevada

Vertebrata		
Chondrichthyes		
		Hybodontidae
Osteichthyes		
	Teleostei	
		Leptolepis nevadensis*
Reptilia		
	Testudines	
		Glyptops sp.
	Crocodilia*	
		cf. Goniopholididae
	Dinosauria	
		Thyreophora*
		cf. Ornithopoda
		Theropoda*
		Indeterminate
Mammalia		
	Multituberculata*	
		Indeterminate

*Denotes taxa reported from previous studies (David, 1941; Clemens et al., 1979; Smith and Ketner, 1976).

Taphonomy

Vertebrate remains from exposures of the Newark Canyon Formation exposed in the Fish Creek and Pancake Ranges are preserved in several different taphonomic modes. Preservational settings in the Pancake Range exposures are dominated by sediment gravity-flow lithofacies, whereas preservational settings in the Fish Creek Range are an array of fluvial and lacustrine settings. All preservational units are consistent with a basin with an active and complex tectonic history (Vandervoort and Schmitt, 1990; Drushcke et al., 2011).

Pancake Range exposures are aerially not very extensive. Fossils recovered from the Pancake section include the material identified as thyreophoran elements, as well as the theropod teeth, a single piece of dinosaur egg shell, and the ornithopod vertebra. Vertebrate remains are found in two lithofacies in the Pancake Range section (Figure

3.8). The first lithofacies is a massive, dark-brown mudrock. There are no pedogenic

features or sedimentary structures. These beds can be tens of meters thick. Bones as well

as other non-bioclasts are found "floating" in the fine-grained matrix. In other portions of

the section, massive mudrocks are associated with stromatolites. Bones from these

horizons are disarticulated (with one exception), and most exhibit some signs of pre-

burial weathering [2-3 on the Behrensmeyer (1978) weathering scale]. The only element

from the massive mudrock lithofacies which is not weathered is a single, partial theropod

tooth (Figure 3.7A).

I interpret the first lithofacies to be both hyperconcentrated flow and lacustrine

deposits. Floating clasts in a massive matrix are consistent with deposits of a

hyperconcentrated-flow diamictite (Zaleha and Weisemann, 2005).
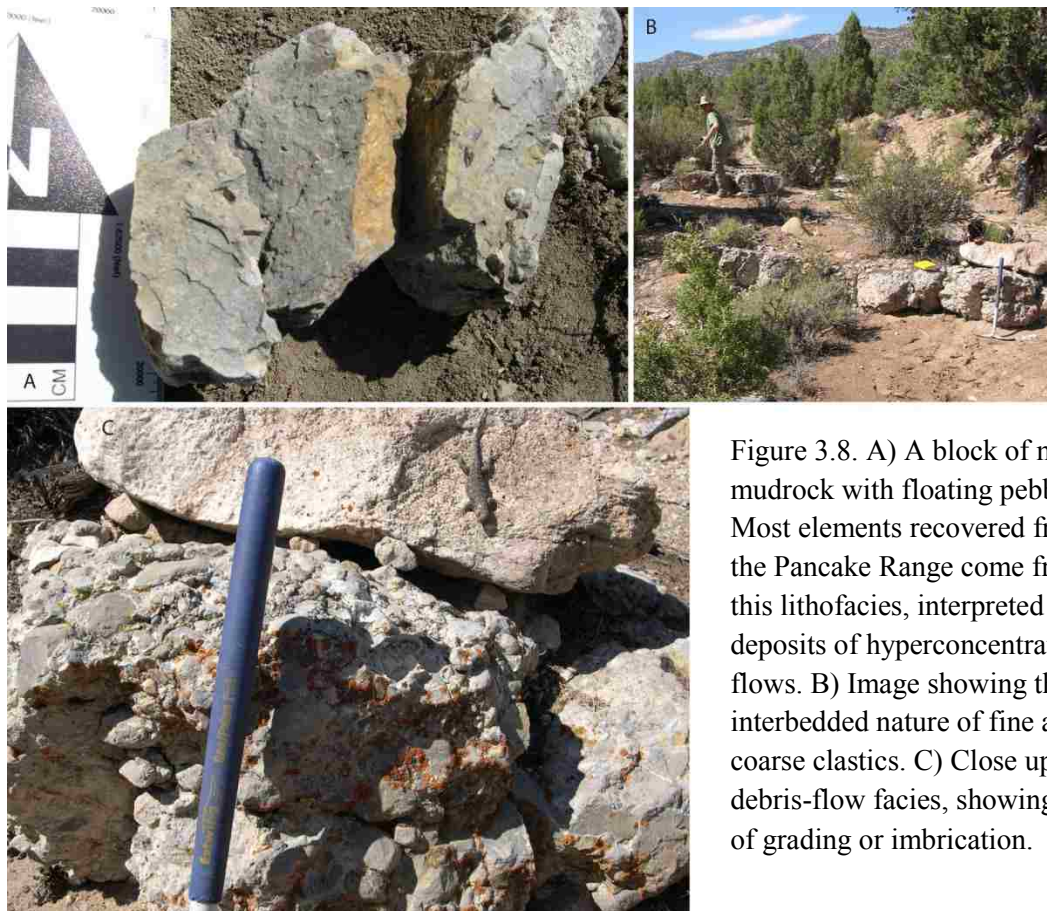
Figure 3.8. A) A block of massive mudrock with floating pebbles. Most elements recovered from the Pancake Range come from this lithofacies, interpreted as deposits of hyperconcentrated flows. B) Image showing the interbedded nature of fine and coarse clastics. C) Close up of debris-flow facies, showing lack of grading or imbrication.

The second vertebrate-bearing lithofacies has produced a single vertebra. This lithofacies is a well-cemented, poorly-sorted, pebble-cobble conglomerate. Clasts are well rounded, with no observed sedimentary structures (Figure 3.8C). These beds are up to 0.5 m in thickness and are interbedded with the fine-grained lithofacies.

I interpret this second lithofacies as being the deposits of debris flows. Non-graded, poorly-sorted conglomerates with no sedimentary structures are consistent with this interpretation.

Unlike the Pancake Range section, the Fish Creek Range section is locally extensive in exposure. Vandervoort (1987) measured a representative section (Figure 3.9) through this area and was able to lithologically correlate it to the Diamond Range type section. He interpreted these exposures to represent fluvial and lacustrine lithofacies (Vandervoort, 1987), and I agree with his interpretation. From the Fish Creek Range, both vertebrate and invertebrate material is found in fluvial and lacustrine lithofacies.

The most productive lithofacies for fossil material consists of lenticular, fine-to-coarse-grained sandstones which exhibit planar and trough cross-lamination. Grains are heterolithic and angular to subangular. Occasional granules are also incorporated into these sandstone bodies. The resistant archosaur elements, the single shark dorsal-fin spine (SCNHM VRD 208), as well as the poorly preserved turtle shell fragments were recovered from this lithofacies. Bone elements from this lithofacies rarely exhibit evidence of pre-burial weathering, although most elements are fragmentary.

I interpret this lithofacies to represent fluvial channels. Trough cross-beds as well as planar bedding are formed by lower-to-upper-flow-regime currents (Miall, 1977).

Elements from this lithofacies are likely allochthonous; they are from the catchment, if not from this particular reach of the paleoriver.
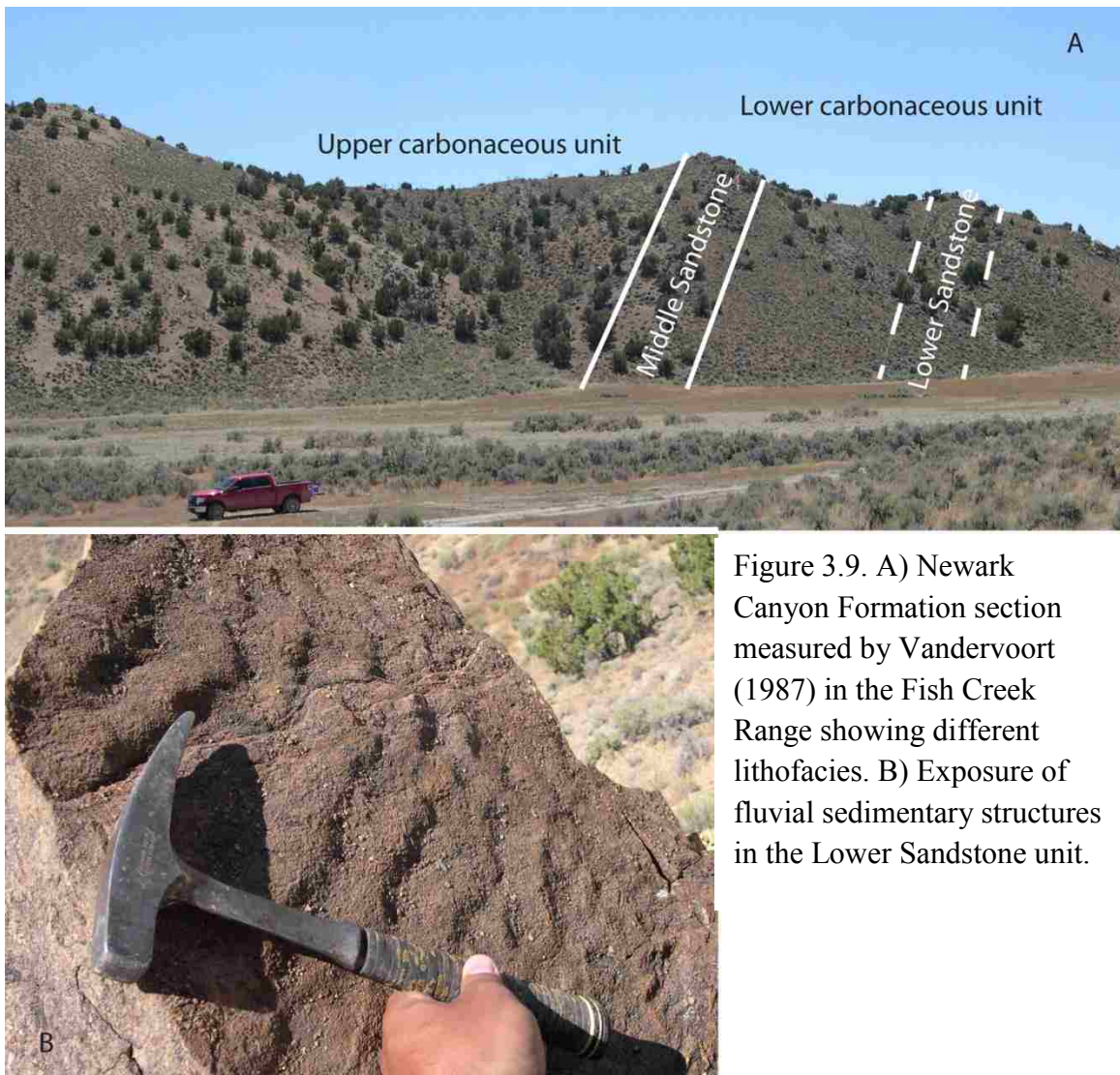
Figure 3.9. A) Newark Canyon Formation section measured by Vandervoort (1987) in the Fish Creek Range showing different lithofacies. B) Exposure of fluvial sedimentary structures in the Lower Sandstone unit.

The second fossiliferous lithofacies consists of calcareous, fine-grained mudrocks. These beds are easily eroded and thus are not well defined in outcrop (Figure 3.9A). These beds range in color from dark brown, to red, to green. Freshwater mussels are common in the dark brown and light brown beds. The red beds contain hard, iron-rich horizons which can be up to a decimeter thick. Although fossils are not as well

preserved, I have recovered most of the vertebrate material from this study in these fine-grained lithofacies.

In agreement with Vandervoort (1987), I interpret these beds to represent both overbank and lacustrine units. Two specimens in particular illustrate this point: SCNHM VRD 203 A & B are an associated ornithopod ungual and metapodial (Figure 3.6). Both specimens exhibit a similar preservational style. One side of each exhibits stage 3-4 weathering on the Behrensmeyer (1978) scale, suggesting that one side of the element was exposed subaerially for several years. The opposite side of each of these elements is weathered at only stage 1-2, showing a side effect. The bones were evidently lying out on the flood plain on one side for several years. Interestingly, on the metapodial (SCNHM VRD 203) a freshwater mussel is attached to the marrow cavity of the specimen (Figure 3.6B). The shell of the mussel is roughly 3 cm long, indicating that after exposure on the surface for a couple of years the bones became submerged long enough for mussel spat to attach and grow to maturity. These two specimens exhibit diagnostic taphonomic indicators of subaerial and subaqueous settings. Most bone from these fine-grained beds is highly weathered (stage 2-3) and is fragmentary. One exception is the turtle elements. Some well-preserved, non-shell, appendicular turtle elements, as well as some large portions of the shell of *Glyptops,* have been recovered. The taphonomy of these fine-grained beds is complex, but it is consistent with the interpretation of both overbank and lacustrine settings, as proposed by Vandervoort (1987).

Discussion

The fauna of the Newark Canyon Formation is similar to that of the Aptian, Ruby Ranch Member of the Cedar Mountain Formation of central Utah (Kirkland et al., 1999). The presence of a freshwater hybodont shark in both units at roughly the same time is consistent with Vandervoort and Schmitt's (1990) hypothesis that there were through-flowing rivers from the Nevadaplano to the foreland basin; this explains how sharks could have made it so far inland as Nevada has had no direct contact with open marine environments since the Jurassic. The general similarity of the two faunas is interesting in that it suggests that the ecological gradient from the more coastal Cedar Mountain Formation to the purely terrestrial, inland, Newark Canyon Formation was gentle enough to allow some of the same taxa to inhabit both basins. Although a wedgetop, hinterland deposit, Vandervoort and Schmitt (1990) and Druschke et al. (2011) do not suggest that the Newark Canyon basin was a high-elevation basin. No paleoaltimetry studies have been conducted on the Newark Canyon Formation, unlike the Late Cretaceous-Eocene Sheep Pass Formation (Snell, 2011), also of east-central Nevada. The paleoaltimetry study of the Sheep Pass Formation does suggest that the Sheep Pass basin was at a high altitude (see Chapter 4). This suggests that uplift of the Nevadaplano in east-central Nevada occurred in post-Aptian time.

My study of taphonomy of the Newark Canyon Formation is consistent with previous sedimentological interpretations of this formation. The one taphonomic mode which occurs in a lithofacies that was not recognized by previous workers is the sediment-gravity-flow-hosted specimens of the Pancake Range. The presence of such a

lithofacies should not be surprising, however, due to the interpretation that the Newark

Canyon basin was a tectonically-active basin with complex topography.

Biogeographically this study helps shed light on a mid-Cretaceous biotic turnover

in western North America. The Cedar Mountain Formation of Utah spans from the

Barremian to the Cenomanian and within these exposures are several members which

preserved different faunas (Cifelli et al., 1999; Kirkland et al., 1998 & 1999). These

faunas record a change from a western North American fauna more closely allied with an

endemic North American fauna similar to that of the Late Jurassic in the Aptian-Albian

Ruby Ranch Member of the Cedar Mountain Formation to a fauna more closely allied

with Asia by the Cenomanian Mussentuchit Member of the Cedar Mountain Formation

(Kirkland et al., 1998 & 1999). With the Aptian Newark Canyon Formation and the

Cenomanian Willow Tank Formation (Bonde et al., 2008), of southern Nevada, I observe

a similar change in faunas consistent with that of Utah. These data support Kirkland et

al.'s (1998 & 1999) hypothesis that this biotic turnover is a continental interchange

phenomenon, and not a regional change; especially since the Nevada records are from

different tectonic settings than the Utah records and cover a much larger geographic area.

Given the aerial extent of Newark Canyon Formation exposures not yet prospected, or

not examined in recent decades, this biota will probably expand, leading to more

comprehensive comparisons to other regional records.

<div align="center">Conclusion</div>

Preservational modes of the Newark Canyon Formation are similar to those of the

Ruby Ranch Member of the Cedar Mountain Formation, suggesting that both units were

deposited in tectonically active regions with fluvial and lacustrine deposition. In addition

to the preservational modes, several geographically sensitive taxa, the hybodont shark

and the turtle *Glyptops*, are common between the two formations. Turtles are used to

infer subtle geographic barriers (Lipka et al., 2006) which are passable by larger more

mobile animals. This implies that the environmental conditions between the two regions

were similar enough for both of these taxa to inhabit both basins. Thus these data support

the null hypothesis that the Newark Canyon Formation must have been deposited at low

elevation, similar to the Willow Tank Formation (configuration A in figure 1.3).

CHAPTER 4

FROG TAPHONOMY OF THE LATE CRETACEOUS-EOCENE SEVIER

HINTERLAND, EAST-CENTRAL NEVADA

Introduction

Late Cretaceous to early Paleogene deposits of the Sevier retroarc foreland basin

system of the western U.S. have yielded a wealth of fossil vertebrate, invertebrate, and

floral remains, however comparatively few paleontological studies exist for coeval

intermontane deposits of the Sevier retroarc hinterland region. The Late Cretaceous-

Eocene Sheep Pass Formation of east-central Nevada represents deposits of a

synconvergent extensional basin within the Sevier retroarc hinterland (Druschke et al.,

2009a,b; Druschke et al., 2011). It occupied what is widely interpreted as a high-

elevation orogenic plateau (Coney and Harms, 1984; Jones et al., 1998; Dilek and

Moores, 1999; DeCelles, 2004). Previous studies of the Sheep Pass Formation type

section have focused on palynology (Fouch, 1979), and invertebrate faunas such as

mollusks (Good, 1987) and ostracodes (Swain, 1987). To date, no vertebrate fossils have

been reported from the >1 km thick Sheep Pass Formation type section.

Ancient high-elevation sedimentary packages are rarely preserved in the

stratigraphic record due to intense erosional processes at high elevations over extended

periods of time. In addition to erosional processes, the Sevier hinterland has been

subjected to several episodes of Paleogene and Neogene extension and volcanism that

have further disrupted the original continuity of synorogenic deposits such as the Sheep

Pass Formation (Druschke et al., 2009a,b; 2011). Given the rarity of ancient high-

elevation sedimentary deposits, it is even rarer to find records of ancient high-elevation

biotas. Thus the Sheep Pass Formation provides a rare opportunity to investigate the preservation of biological remains in high-elevation settings.

During the course of this study, I have recovered more than a dozen frog specimens from the Sheep Pass Formation type section, many of which are fully articulated, as well as an extensive frog bonebed. Frogs are the only vertebrates identified within the Sheep Pass Formation type section to date, but I also document crayfish, trace fossils, and scattered plant remains, in association with previously documented ostracodal, and molluscan faunas. These discoveries shed light on an interesting pattern of community structure and preservation within the Sevier hinterland during the latest Cretaceous and Paleogene. In this paper I describe the fossil material collected from the Sheep Pass Formation type section and interpret the preservational modes of the fossils. I also consider what this fossil material may reveal about the ecology and evolution of this long-lived, high-altitude lake basin.

If the biota and preservational modes of the Sheep Pass basin suggest a cool climate during a global climatic optimum then that would support previous interpretations that the region was uplifted to a high elevation, thus invalidating the null hypothesis and supporting my alternative hypothesis. If the biota and preservational modes of the Sheep Pass basin suggest a warm, sub-tropical climate then the null hypothesis will not have been invalidated through this entire study and my alternative hypothesis can be rejected.

Geologic Setting

The Sevier orogen is typified by thin-skinned thrust faulting and resultant crustal thickening in the Sierra Nevada retroarc region, that resulted from prolonged Jurassic to

Paleogene eastward subduction of the oceanic Farallon plate beneath the western margin of North America (DeCelles, 2004, and references therein). Following maximum crustal thickening in the Late Cretaceous, east-central Nevada is generally envisioned as part of a high-elevation orogenic plateau (Coney and Harms, 1984; Jones et al., 1998; Dilek and Moores, 1999, DeCelles, 2004). Synconvergent, surface-breaking normal faults documented within the Sheep Pass Formation suggest that syncontractional extension had initiated by latest Cretaceous time in the Sevier hinterland of east-central Nevada, resulting in the establishment of a series of basins generally analogous to the high-elevation graben systems of the modern Puna-Altiplano and Tibetan Plateau (Druschke, 2008; Druschke et al., 2009a,b). In support of a high-elevation interpretation, clumped stable-isotope analyses of lacustrine carbonates within the basal Sheep Pass Formation suggest a 2.6 to 3.5 km paleoelevation for east-central Nevada during the latest Cretaceous and earliest Paleocene, perhaps 2.2 km higher than the foreland basin in Utah at the time (Snell, 2011).   The Sevier hinterland was subsequently affected by a southward younging sweep of middle to late Eocene extension and associated volcanism (Armstrong and Ward, 1991; Gans et al., 2001) that reactivated elements of the Sheep Pass basin system (Druschke et al., 2009a). Most recently, large-magnitude Neogene Basin and Range extension subjected the Sheep Pass Formation to differential uplift, erosion, and burial beneath younger extensional basins.

The Sheep Pass Formation, first described by Winfrey (1958, 1960), is a sedimentary package that forms isolated outcrops in various mountain ranges of east-central Nevada (Figure 4.1). The Sheep Pass Formation is divided into members A-F based largely upon lithology (Figure 4.2). Previous workers have determined that the

primary depositional settings of the Sheep Pass Formation represent lacustrine, alluvial

fan, and fluvial settings (Winfrey, 1958; Winfrey, 1960; Kellogg, 1964; Fouch, 1979;

Druschke, 2008).

 While the current study documents the first identifiable vertebrate remains from

the Sheep Pass Formation type section, previous studies have identified vertebrate

remains from other localities within the Sheep Pass Formation. Fouch (1979) identified

the remains of the insectivore-like mammal *Nyctitherium* within Paleocene to Eocene

lacustrine carbonates of the Grant Range (Figure 4.1). Emry (1990) identified a

mammalian fossil assemblage (also with bits of anurans) of Eocene (Bridgerian) age

within the northern Egan Range Elderberry Canyon location. Of most direct relevance to

the current study, Hecht (1960) identified the remains of two fossil frogs recovered from

a petroleum exploratory drill core located just west of the Sheep Pass Formation type

section in White River Valley. These specimens were identified as a new species,

Eorubeta nevadensis, and were recovered from a lacustrine limestone correlative to

Member B or C within the Sheep Pass Formation type section. Hecht (1960) noted that

frog population densities would have to be very high to preserve two specimens within a

single core, although it would take nearly fifty years for specimens to be found in outcrop

within the Sheep Pass Formation type section.
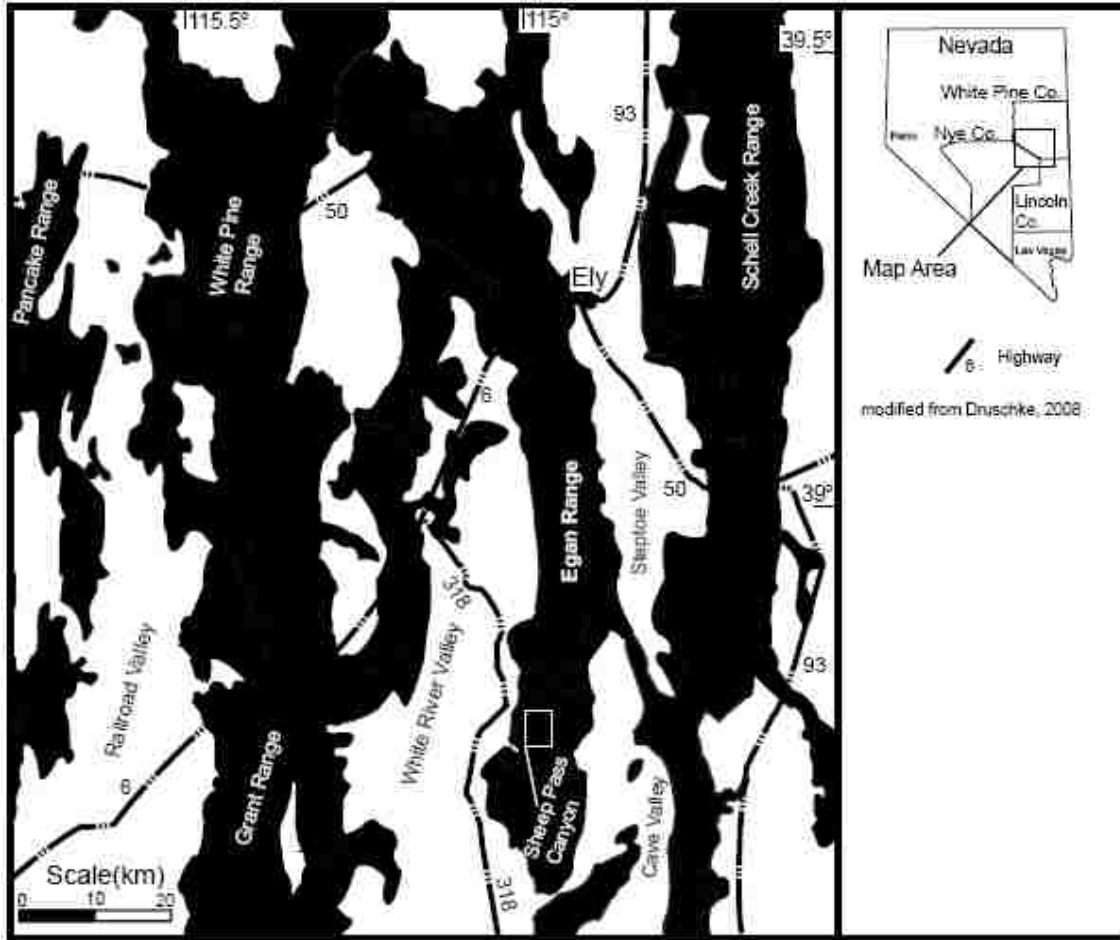
Figure 4.1. Map of east-central Nevada modified from Druschke (2008), showing mountain ranges in black and valleys in white. Sheep Pass Canyon is in the white box at the south end of the Egan Range.
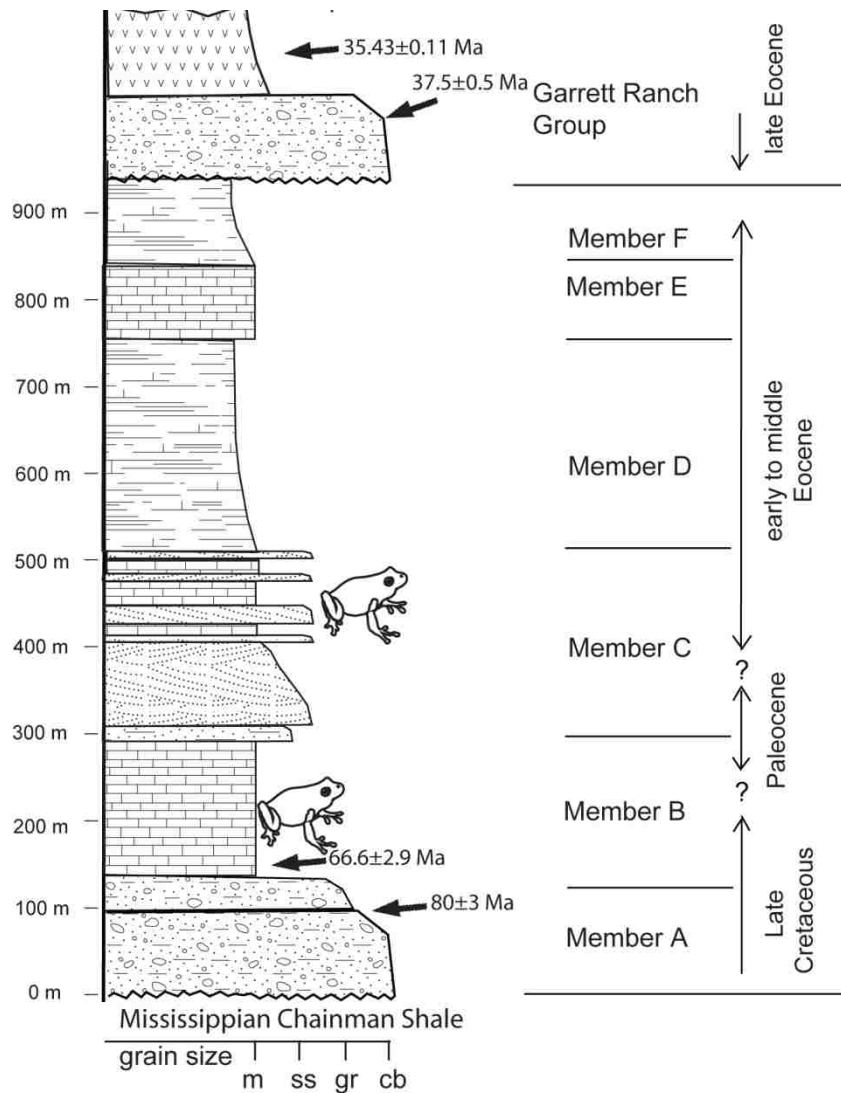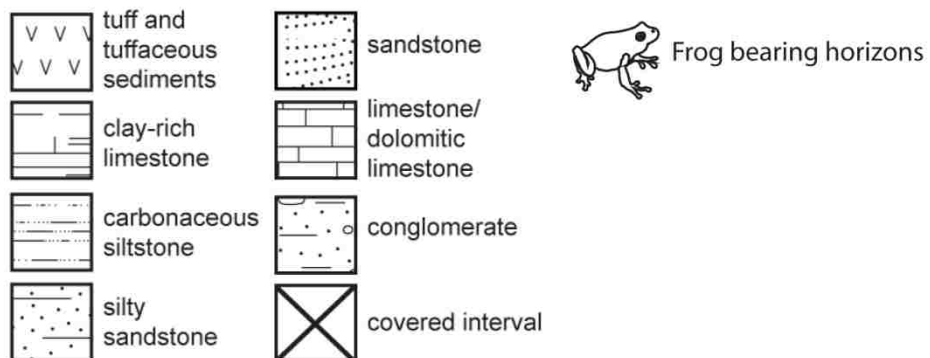
Figure 4.2. Stratigraphic column of the Sheep Pass Formation type section, adapted from Druschke (2008). Of interest to this study are Members B & C. Frog symbol denotes stratigraphic intervals where fossil frogs have been recovered.

Methods

Prospecting and Surface Collection

Fossil localities were discovered by prospecting exposures of the Sheep Pass Formation type section within Sheep Pass Canyon. I mapped all fossil sites, including isolated elements, on a topographic map, recorded their GPS locations, and then collected the specimens.

Only surface collections were made; no excavations were conducted. Fossil material was noted as float or as *in situ*. *In situ* material was discovered by splitting the exposed mudrocks with a rock hammer. The collected specimens were taken to SCNHM for preparation and curation. Field work was conducted under BLM permit # 8270(NV040) 2009.

I placed the fossil localities within the stratigraphic framework of Druschke (2008). This allowed me to identify which members of the Sheep Pass Formation are fossiliferous. All fossils were collected from Member B (Late Cretaceous-Paleocene) and Member C (Paleocene-Eocene). I recorded sedimentological data for the purpose of determinating depositional environments.

Taphonomic Analysis

I recorded as much taphonomic information as possible in the field. This includes spatial distributions of specimens, articulation and/or associations, as well as bone-bone contacts, lack of contacts, complete disassociation, breaks, break style, and alteration halos. I obtained data on surface modification back in the lab, after preparation of elements, because such features are often obscured by matrix (Eberth et al., 2007). Surface modification data include weathering (after Behrensmeyer, 1978), abrasion (after Shipman, 1981), tooth marks, bioerosion, trample marks, and the nature of breaks (e.g.,

faults, blocky, spiral). Trend and plunge data of long-bone elements are used to determine whether elements have been aligned due to fluid flow, or whether the bones are oriented randomly. Random orientations may reflect rapid burial (Eberth et al., 2006) or trampling (Fiorillo, 1989).

<u>Curation</u>

Specimens were prepared at the Sierra College Natural History Museum, Rocklin, California, USA. Preparation involved removal of specimens from packaging and carefully noting orientation data on the packaging so that orientation data were not lost in the lab. Matrix was removed with small hand tools (e.g., dental picks and toothbrushes), and in some cases an air scribe. As matrix was progressively removed, polyvinyl acetate was applied in order to protect/stabilize the element. Broken elements were reconstructed using either cynoacrylate or white glue. Specimens that displayed important patterns along natural breaks were not reassembled.

Prepared specimens underwent further taphonomic anaylsis, after which they were placed into the appropriate curation tray or appropriate container/cradle. All specimens from this project are reposited at the Sierra College Natural History Museum, Rocklin, California, USA.

I first describe and interpret the paleontology of Member B, followed by a description and interpretation of the paleontology and taphonomy of Member C. These descriptions and interpretations are summarized in Table 4.1.

Member B Paleontology

Member B of the Sheep Pass Formation type section has produced a diverse biota of plants, invertebrates and vertebrates. Ostracods are the most numerous invertebrates,

and anurans are the sole vertebrates recovered to date. In addition to the body fossils, there are also some invertebrate traces preserved within Member B. Fossils are found in at least three different lithofacies: dolomitic clayshales, dolomitic microbialites, and tempestite beds.

Plants

There are at least three types of plant body impressions. The first consists of portions or brachs of a larger organ, 1 cm long and up to 1.5 mm in diameter. Perpendicular to the long axis are shorter (0.5-0.75 cm long) appendages. The second type of body impressions are long (up to 20 cm), 2-3 cm wide, with parallel structures along the long axis of the impression (Figure 4.3). These are the best preserved plant specimens. They maintain their width from the base until they finally taper to a tip at their distal end (Figure 4.3). These two types of plant fossils are found in a very fine dolomitic clayshale which contains only plant fossils; no animal body or trace fossils are present. The final type of plant body impression is a single, unidentified, angiosperm leaf roughly 5-6 cm from petiole to the tip of the leaf (Figure 4.4). There is a dominant primary vein which runs from the petiole to the tip of the leaf. There are arcuate secondary veins which come oppositely from the primary. The margin of this leaf is entire and is eucamptodromous in morphology (Figure 4.4) (cf. Hickey, 1973). This specimen is found in an irregularly laminated, dolomitic mudstone.
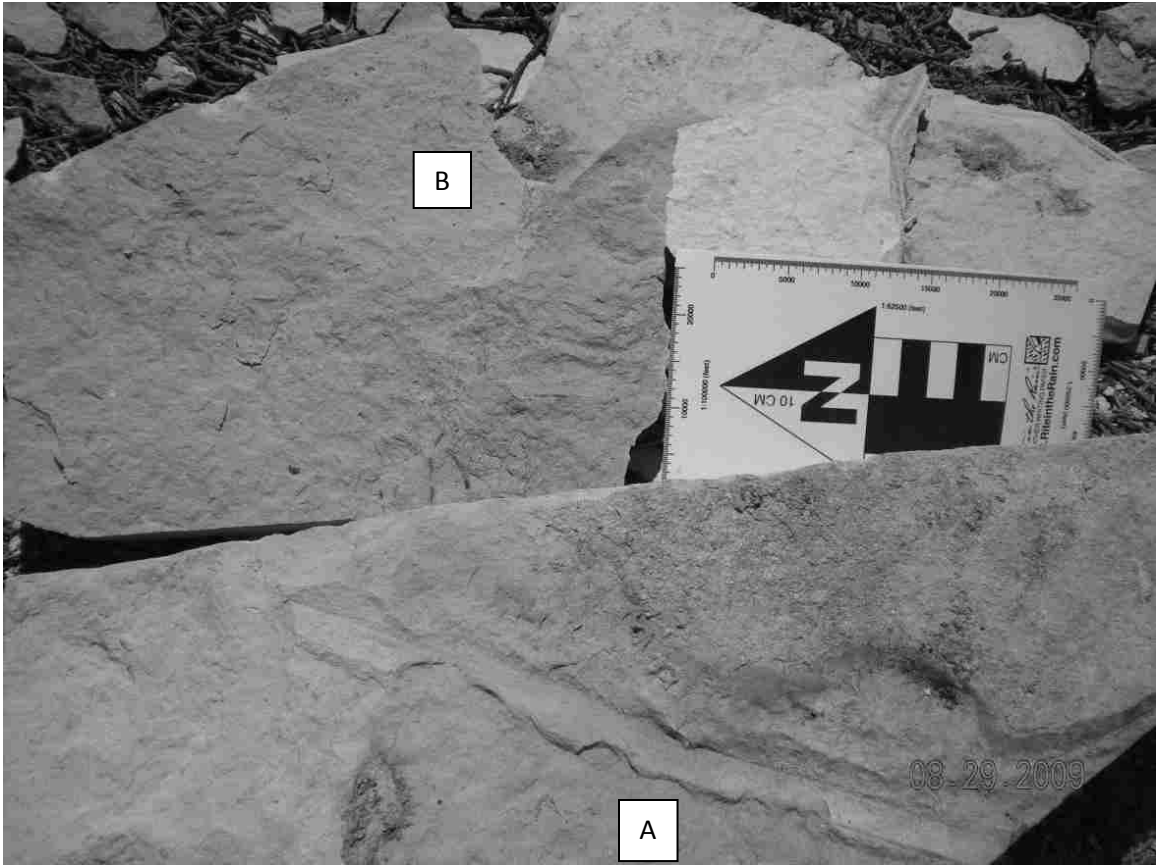
Figure 4.3. Plant impressions within very fine, dolomitic clayshale. A) Refers to the long plant impressions, B) refers to the smaller gymnosperm impressions.
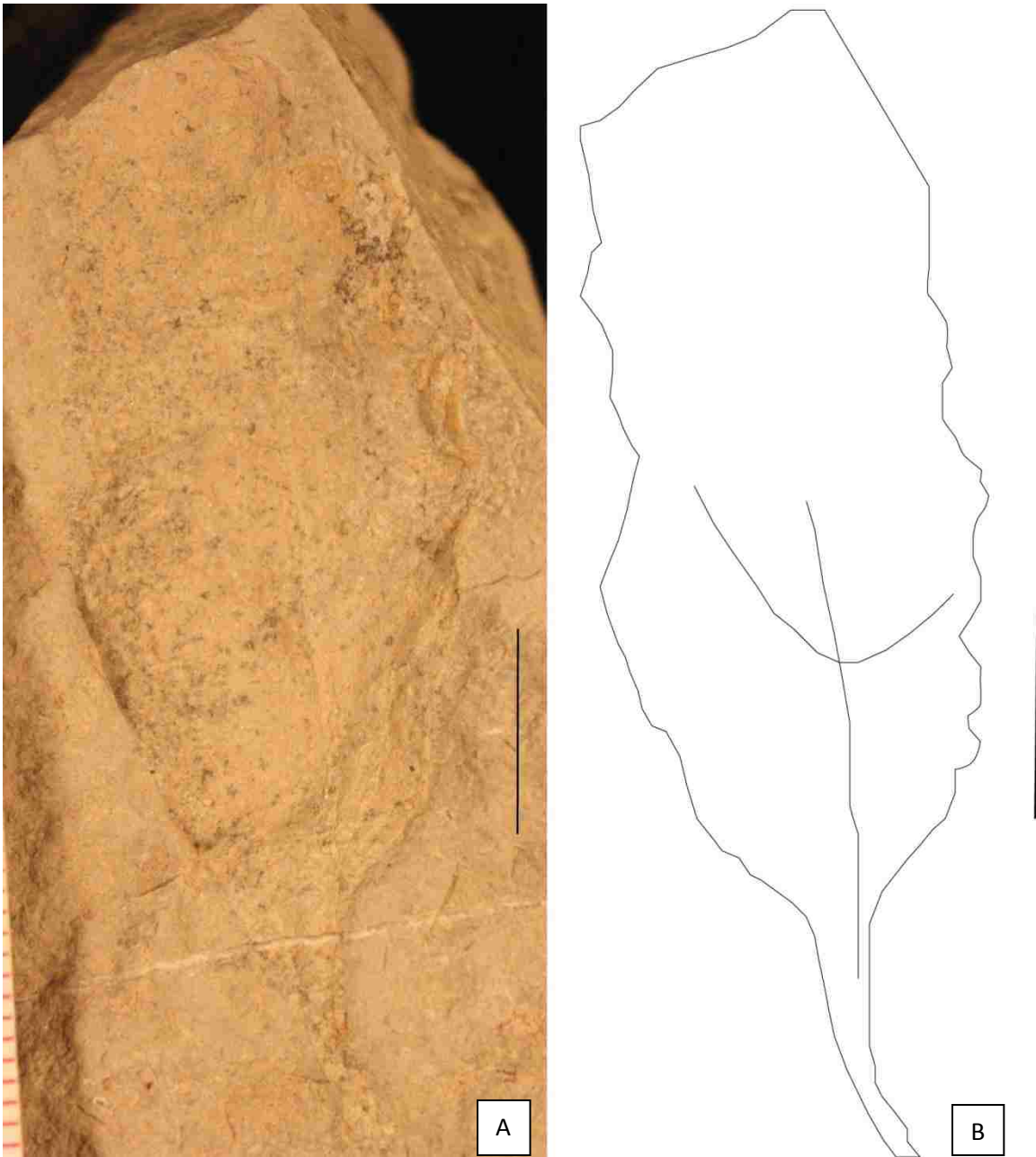
Figure 4.4. A) Leaf impression within microbialite facies of Member B. B) Outline of leaf, primary vein and secondary. Scale is 1 cm.

<u>Invertebrates</u>

There are numerous invertebrate fossils in Member B of the Sheep Pass

Formation, including body fossils of mollusks and crustaceans. Bivalves are typically

less than a centimeter in diameter and are found isolated in planar-laminated, dolomitic

mudrock lithofacies, or they are found concentrated along with fine-grained mudstone

intraclasts, in irregularly bedded dolomitic mudstone.

Ostracods are extremely abundant in planar laminated, dolomitic mudrock

lithofacies (Figure 4.5). In some of these beds ostracods are the only fossils preserved in

abundance. In other beds they occur in close association with vertebrate remains. In

some instances ostracods are preserved in carapace-to-bone contact (Figure 4.8).

Ostracods present in this unit are *Clinocypris? sp., Paracypridopsis? sp*., and *Cypridea

bicostata* (Swain, 1987).
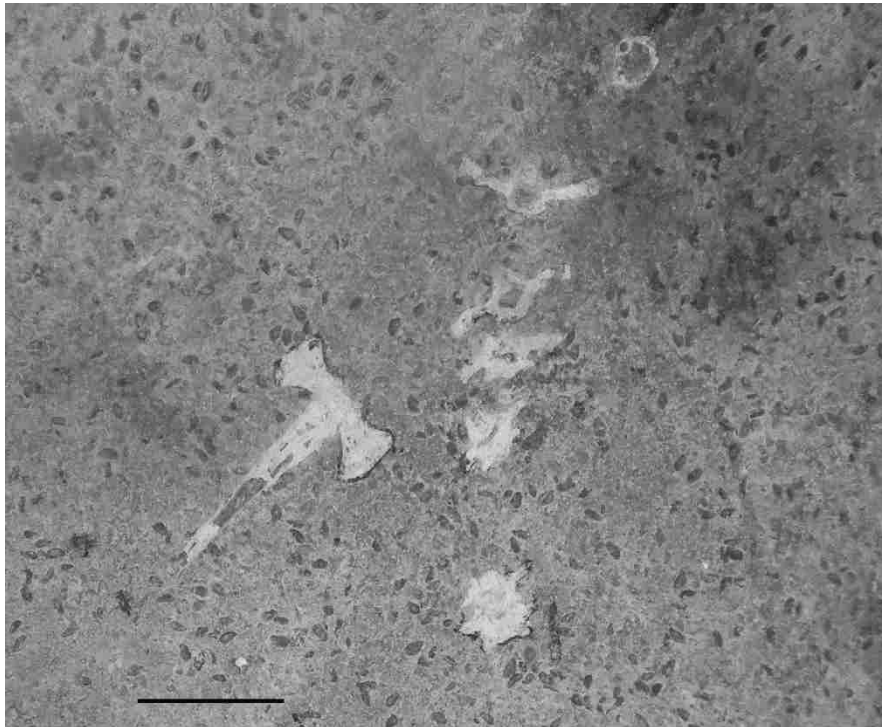
Figure 4.5. Abundant ostracods (tiny dark grains) in horizontally laminated dolomitic
clayshale in Member B, associated with disarticulated frog vertebrae (larger white
objects). Scale is 1 cm.

Occasional impressions of crayfish carapaces are found within the dolomitic mudstone lithofacies, in both the planar-laminated and crinkle fabric beds. The impressions are typically partitioned into 4-5 segments (Figure 4.6). These attached segments are all slightly concave and are nearly a centimeter in length and a few millimeters in width. The specimen shown in Figure 4.6 is articulated with a more massive structure divided along a midline and oriented at 90° to the former structure. I interpret these structures to be articulated abdominal somites, part of the telson and posterior, dorsal parts of the cephalothorax of a crayfish.
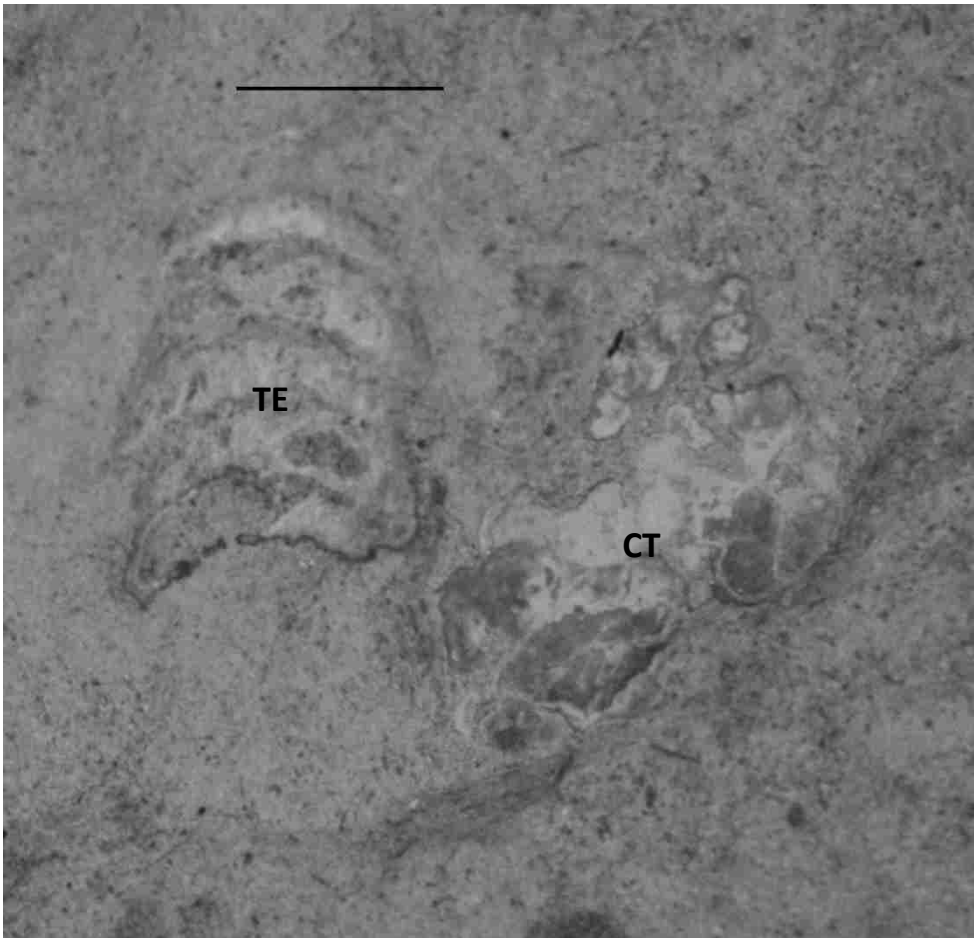
Figure 4.6. Impression of a molted crayfish exoskeleton found in the horizontally-laminated dolomitic clayshale of Member B, scale is 1 cm. CT-cephalothorax, TE-telson.

Vertebrates

Numerous frog specimens have been recovered from Member B of the Sheep Pass Formation within the Sheep Pass type section. These specimens are found stratigraphically throughout the section (Figure 4.2). All specimens are preserved within dolomitic mudstones. Specimen SCNHM VAF 3 is a nearly complete, articulated frog (Figure 4.7). It occurs on a bedding plane within a mudstone exhibiting crinkle sedimentary fabric. The specimen does not have any pre-burial weathering or abrasion of elements; there is, however, significant modern weathering. There is also significant modern, irregular, blocky breakage of many elements. The presacral vertebrae are absent with only a few portions of the transverse processes present. Distal leg and pes elements are still encased in matrix; they have not been prepared out of concern for their fragility.

Figure 4.7. Fully articulated frog skeleton (SCNHM VAF 3) in microbialite facies of Member B. Scale is 1 cm.

Both manus are mostly missing; only three phalanges on the right manus remain. Approximately half of the cranium is missing; the basicranium is preserved, but the majority of the dentary and maxilla are gone. The pectoral girdle is complete, and elements appear to be closely associated, if not articulated. This specimen is found isolated, with no other individuals preserved in the same horizon.

Frog specimen SCNHM VAF 32 A&B (Appendix A, Figure A.1) is also preserved in a dolomitic mudstone which exhibits a crinkle fabric and irregular lamination. This specimen is a part and counterpart of an articulated animal. Due to modern weathering processes all of the original bone is now gone and only an impression remains. All elements are in life position. The impression retains very good detail of the original bone, including tooth impressions from the dentary.

Specimen SCNHM VAF 31(Appendix A, Figure A.2) represents an impression of a nearly complete frog. Due to modern weathering processes the original bone is gone, and the cranium and right arm are missing. The rest of the animal is articulated, with the lone exception being that the urostyle has been dislodged and was resting at an angle against the left ilium. It is rare in this unit to have disarticulated elements in mudstones exhibiting crinkle fabric.

Specimen SCNHM VAF 27(Appendix A, Figure A.3) is preserved in a planar laminated, dolomitic mudstone, with associated ostracods. This specimen is partially disarticulated, however elements remain in association. The disarticulation pattern is random. Elements of this specimen have undergone significant modern weathering and breakage. Much of the cranium and right arm are weathered away. The hind limbs are well preserved, but the distal elements are obscured by matrix.

Specimen SCNHM VAF 13 A&B (Appendix A, Figures A.4 & A.5) is a nearly complete animal. Most cranial and appendicular elements are articulated. The pes are complete and articulated, the phalanges of the right ped are preserved in a curled posture. The dentary is slightly ajar from the cranium. The cranium and dentary are slightly offset at a slight angle from the midline of the animal. The vertebral column is not well preserved and one vertebra is visibly disarticulated and found posterior to the pelvic girdle. There are abundant ostracods associated with this specimen. This animal is also preserved in a planar laminated dolomitic mudstone.

Specimen SCNHM VAF 28 A&B (Figure 4.8) is also preserved in a planar laminated dolomitic mudstone, with abundant ostracods. Ostracods are in direct contact with bone elements. This specimen is mostly articulated, with some elements disarticulated but in close association. The pattern of disarticulation appears to be random. The cranium is slightly offset from the line of the vertebrae. The only breaks on this specimen were the result of splitting the slab in which it was discovered.

Specimen SCNHM VAF 26 A&B (Appendix A, Figure A.6) are preserved nearly identically to specimen SCNHM VAF 28 A&B, in a planar bedded dolomitic mudstone, with abundant ostracods. The only difference is that SCNHM VAF 26 does not have ostracods in direct contact with bone elements. SCNHM VAF 26 is also disarticulated in a similar pattern as SCNHM VAF 28, the cranium is slightly ajar, and the specimen is mostly articulated with some distal elements disarticulated but in close association.
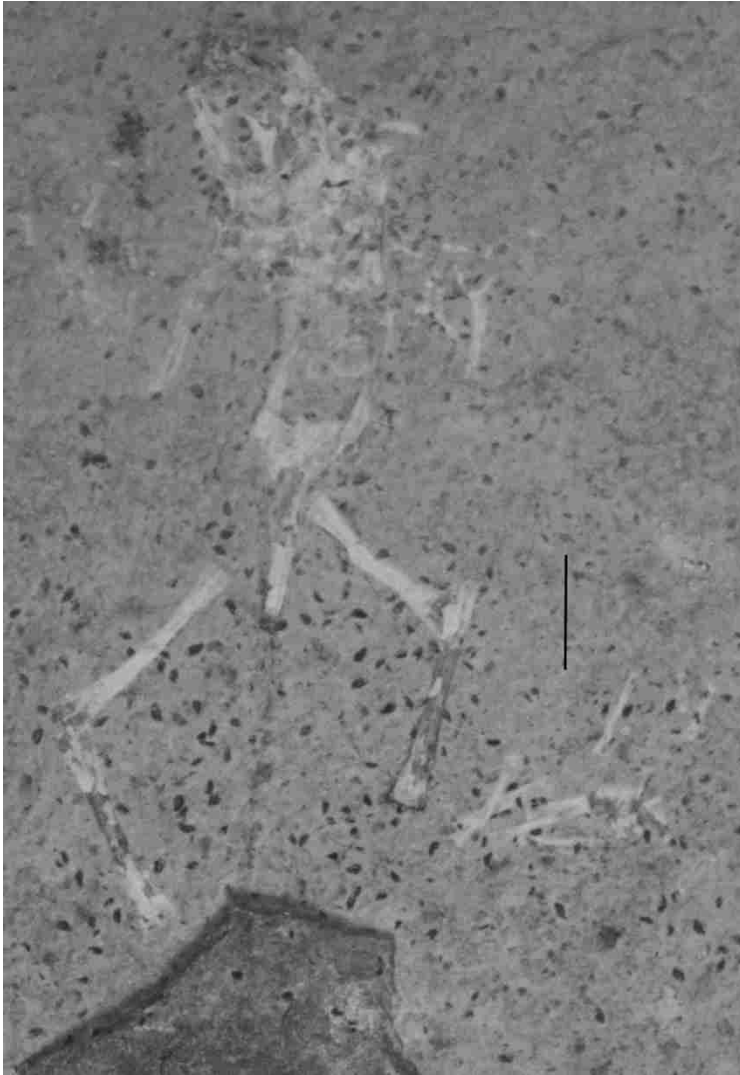
Figure 4.8. Articulated frog (SCNHM VAF 28) skeleton found in horizontally laminated dolomitic clayshale of Member B showing ostracod swarming. Some ostracods carapaces are found in direct contact with bone, a sign of ostracod scavenging. Scale is 1 cm.

SCNHM VAF 15 A&B (Appendix A, Figure A.7) are a part and counterpart situated along a bedding plane. This skeleton is disarticulated. Limb bones are visible, as is the cranium with visible maxillary teeth. Orientation of the bones appears to be erratic. Associated with this specimen are abundant fine-grained clasts, similar in composition to the underlying, very fine claystone. Bone preservation is excellent, with pristine surfaces; only occasional modern blocky breakage obscures elements.

SCNHM VAF 39 (Figure 4.5) consists of an associated, but disarticulated, urostyle and seven vertebrae. There are abundant ostracods associated with the

specimen. Orientation of the skeletal elements appears to be random. A lone metapodial is the only appendicular element preserved. There are no signs of weathering or abrasion on elements. Elements are preserved in a planar-laminated, dolomitic mudstone.

Trace Fossils

There are numerous trace fossils preserved within the dolomitic mudrocks of Member B. One type consists of randomly sinuous, continuous trails (Figure 4.9), roughly 0.8-1 cm wide and U-shaped in cross section. These trails are observed only in irregularly laminated mudrocks with crinkle fabric. Another common trace fossil stands out in slight positive relief, ~1 cm, along bedding planes of relatively flat laminated mudrock. In plan view, these are nearly perfectly circular, with diameters ranging from 5-7 cm. In the lab, one of these traces was cut in half to expose the internal structure (Figure 4.10). Along the outer edge of the trace, the mudrock becomes darker in color and is lined with numerous ostracods along the margins. In between the dark margins are very fine menisci of mudrock infilling the trace, with few ostracods. These traces are found only in the ostracod-rich, horizontally laminated mudrocks, where they are common. These traces match the characteristics of crayfish burrows (Anthony Martin, pers. comm., 2010).

Figure 4.9. Sinuous invertebrate feeding trace in dolomitic mudstone exhibiting crinkle-fabric. Rock hammer head for scale. The trace varies between 0.8 and 1 cm across.
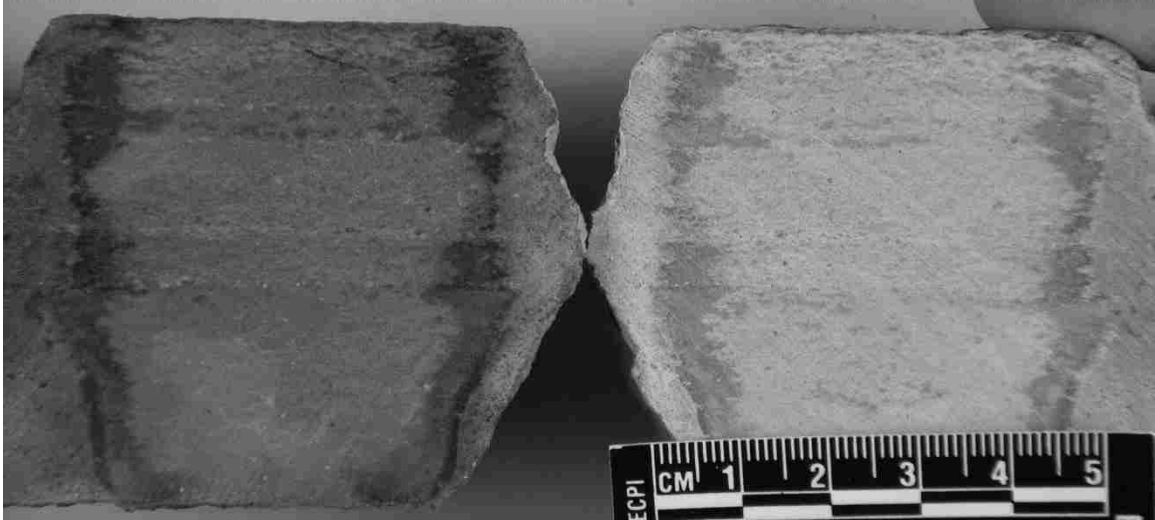
Figure 4.10. Cross-sections of a crayfish burrow, cut perpendicular to bedding. Note the fine meniscate lamina; darker spots within the menisci are ostracods. The darker margin is interpreted to be the agglutinated edge of the burrow.

Member B Taphonomy

Member B preserves plants in two taphonomic modes, in laminated dolomitic clayshale and in irregularly bedded crinkle fabric in dolomitic mudstone. Body fossils and partial body fossils are represented. Plant fossils are found in two localities in two separate lithofacies. The partial plant remains, which are tentatively assigned to gymnosperms, and the long plant body fossils are preserved in a very-fine, planar-laminated, dolomitic clayshale. There is no carbonaceous material left, only impressions. The long body fossils are likely autochthonous and represent a period of time when lake level was low enough for these types of plants to subsist in the middle of the basin. Lower and higher in the stratigraphic section the water levels were probably too deep for such plants. This interpretation is supported by the absence of fossil gymnosperms higher or lower in the section. Allochthonous macrofloral material rarely travels farther than 50 meters from the source plant (Ferguson, 1985); thus the shore of the paleolake

can be interpreted to have been within 50 m of the sites where these fossils were deposited.

One of the other lithofacies, which preserves the previously mentioned eucamptodromus-leaf fossil, is a crinkle-fabric, irregularly laminated, dolomitic limestone. This leaf is slightly deformed, possibly due to a load on the middle of the specimen, or it may have already been partially curled upon sinking. This specimen was found in association with frog remains and is the only plant fossil known from the crinkle-fabric-bearing limestones. I interpret this leaf to be allochthonous, having been transported out into the lake to settle onto a microbial mat. The scarcity of plant fossils does not allow a more comprehensive picture of the plant life within the basin in which the Sheep Pass Formation type-section was deposited. Little can be said about the plant record, as to what the surrounding foliage was like, nor can these fossils lend themselves to paleoclimatic analysis.

Invertebrate remains and traces in Member B are typically found in a single lithofacies, the planar-laminated, dolomitic limestone. Ostracods tend to be congregrated, with dozens of individuals in a small area (less than a meter square). Previous workers concluded that ostracods (Swain, 1987) and mollusks (Good, 1987) from Member B are indicative of an alkaline, open-lake environment. In some instances the ostracods are found in direct contact with vertebrate bones. The most dense accumulations of ostracods are found in and around the cranium and other bone elements of frog fossils. This suggests that either the ostracods accumulated after the soft tissue of the frog was already decomposed or, more likely, that the ostracods swarmed the frog carcass to scavenge the carrion. Ostracod swarming is a diagnostic sign of scavenging in

the fossil record and in the modern (Wilkinson et al., 2007). Other than being found in close association with vertebrate remains, ostracods are found scattered along bedding planes of the planar-laminated limestones.

Another occurrence of ostracods in Member B is along the agglutinated edges and meniscate infilling laminae of vertical crayfish burrows. These specimens may either be accumulations of ostracods at normal background rates, or they may be the remains of individuals preyed upon or scavenged by crayfish. A study by Gutierrez-Yurrita et al. (1998) of crayfish gut contents showed that ostracods account for about 10% of crayfish diet. Ostracods are not found in any other lithofacies in Member B.

Segmented impressions (Figure 4.6) and more massive impressions in Member B represent the molted telson and abdominal somites of crayfish. The specimen shown in Figure 4.6 probably represents a molted cephalothorax (figured in Fetzner, 2002). Crayfish impressions have not been found preserved in life-like posture, which leads to the conclusion that they are molted skeletons. Further, molting in crustaceans, occurs many times throughout an animal's life, thus providing a higher chance of finding molted carapaces than complete individuals. Also, as described above, traces of probable crayfish burrows occur in the planar-laminated dolomitic limestones (Figure 4.10). The rims of these structures are preserved in positive relief and are nearly circular in plan view, which is characteristic of crayfish burrows, and distinct from other burrowers such as lungfish (Anthony Martin, pers. comm., 2010).

Other invertebrates preserved in Member B include occasional gastropods and numerous bivalves. Good (1987) identified this mollusk assemblage as a *Valvata, Hydrobia*-Sphaeriidae association; along with the ostracod assemblage, these taxa

support the interpretation of an open, alkaline-lacustrine setting (Good, 1987). Modern analogous mollusk assemblages can be found in temperate lakes of North America (Good, 1987).

Bivalves are preserved in two taphonomic modes. The less common mode of preservation is as isolated, articulated specimens in planar-laminated, dolomitic limestone. These specimens are interpreted to be the result of attritional accumulation over time. The second, and more common, preservational mode is articulated and disarticulated valves found amongst irregular clasts of underlying clayshale strata in an otherwise silty, irregularly-bedded, dolomitic limestone. This preservational style is interpreted to represent tempestite beds. The clasts of mudrock are interpreted to be mud rip-up clasts. That, coupled with the dense accumulation of articulated and disarticulated specimens, suggests that at least some of the valves were remobilized. The irregular bedding, disarticulated valves, and mud rip-ups indicate that these beds represent periods of increased energy in the system. These beds probably do not represent fluvial influxes as there are no signs of sedimentary structures indicative of fluvial processes, such as clast imbrications or cross-laminae.

Vertebrates are preserved in three taphonomic modes in Member B. The first includes the individuals preserved within the crinkle-fabric, dolomitic mudstones. The lack of evidence of exposure and transport supports an interpretation that frogs in this taphonomic mode died of attrition through time. This is supported by the stratigraphic distribution of specimens which had settled onto microbial mats in life position and were subsequently buried and preserved. Actualistic studies of fish carcasses reveal that water temperatures must be below 15°C in order for a carcass to sink (Elder, 1985). In another

actualistic study Dodson (1973) showed that a frog bloated and floating in a tank will begin to decompose and disarticulate after 21 days. Therefore, the articulated frog specimens encountered in this study most probably sank to the bottom within three weeks of death. The lack of scavenging could be attributed to anoxic or dysoxic conditions; however, the relative abundance of invertebrate trace fossils within these crinkle fabric horizons suggests that, even if bottom waters were relatively dysoxic, oxygen levels were not low enough to deter potential invertebrate scavengers from feeding along the bottom of the lake. Oil chemistry of petroleum sourced from the Sheep Pass Formation Member B, suggests that the lake was stratified and anoxic to hypersaline (Ahdyar, 2011). Perhaps some of these more intact microbialites were formed close to the anoxic-dysoxic boundary further deterring scavenging.

The second taphonomic mode is similar to the first in that specimens are typically nearly articulated; the difference is that there are no signs of microbial mats in the form of crinkle fabric. This mode is hosted in a planar-laminated, dolomitic limestone and, unlike the first vertebrate taphonomic mode, these are the horizons which contain abundant ostracods. Many of the frogs preserved in this lithofacies are also slightly more out of "life position" than those in the microbialites, suggesting that they may have been subject to additional transport or scavenging. As mentioned above, some of these frogs appear to have been scavenged by ostracod swarming. Other specimens with elements displaced in random directions from the main part of the animal are consistent with scavenging (Elder and Smith, 1984). Given that these frogs are also almost completely articulated supports the above interpretation that they must have sunk within three weeks of death (Dodson, 1973). In order to sink without bloating and disarticulating, water

temperature must have been below 15°C (Elder, 1985) for at least part of the year. Given the stratigraphic distribution of this lithofacies, I interpret this taphonomic mode to also be attritional, as frogs died and settled to the bottom through time.

The final taphonomic mode of frog elements in Member B is related to the taphonomic mode described for bivalves in the beds interpreted as tempestite horizons. These frog elements are typically found isolated and associated with disarticulated bivalve valves and mud rip-up clasts. These elements are interpreted to be reworked frog elements from either the lake bottom or underlying sediments. Dodson (1973) showed that even frog bones which have been submerged for long periods of time were still easily transported.

Member C Paleontology

A number of anuran specimens have been recovered near the top of Member C (Figure 4.2). In addition to anurans, this member preserves abundant mollusks and ostracods. The most fossiliferous lithofacies in Member C are planar-laminated, silty limestones and calcareous siltstones. Less common in the member are trough-cross-bedded and ripple-marked sandstones, trough-cross-bedded conglomerates, and rare oncolitic limestones, but to date these lithofacies have not produced any vertebrate fossils.

Invertebrates

By far the most numerous invertebrates in the fossiliferous beds of Member C are ostracods (Figure 4.11). These remains are found within thin beds of planar-laminated silty limestone, either as the only fossil material present or in association with bivalves and/or anurans.
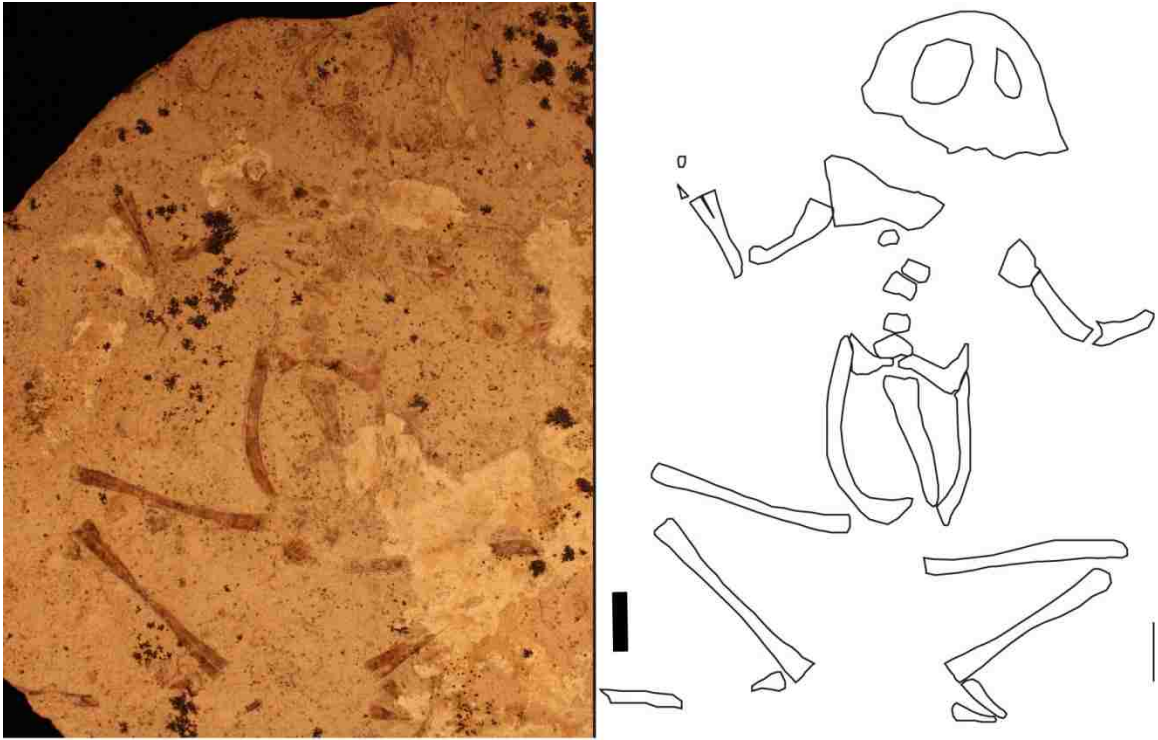
Figure 4.11. Fully articulated frog (SCNHM VAF 4)
from calcarerous siltstone of Member C. All of the very
small, dark structures are ostracods. Scale is 1 cm.

Bivalves are common in fossiliferous lithofacies, either as isolated shells or in
dense concentrations. Most specimens are less than a centimeter in their longest
dimension. Bivalves are always found in association with ostracods in fossiliferous
horizons in Member C. Bivalves are predominantly articulated, a sign of low energy
conditions (Good, 1987)

Vertebrates

Numerous frog specimens were recovered from Member C. SCNHM VAF 4
(Figure 4.11) is a nearly complete, articulated frog found in a planar-laminated,
calcareous siltstone. This specimen was found within the fossiliferous, silty limestone

lithofaces and is associated with abundant ostracods and bivalves. There is no evidence of pre-burial, subaerial weathering or abrasion of elements, however many elements display irregular, blocky breakage. There are also abundant calcite rinds over many elements, and those which are not covered by a calcite rind have undergone significant modern weathering. Manus elements have not been preserved in this specimen; pes elements are fragmentary and articulated, or at least found in close association. The right maxilla and dentary are largely missing and are represented by a calcite rind which had coated the underside of those elements. The posterior of the urostyle is skewed strongly to the right side of the individual. Missing elements and damaged elements are attributed to modern weathering processes. Also represented in the same rock specimen is the articulated tibiofibula and femur of another individual, the rest of this second individual is missing due to a natural fracture in the rock.

Another specimen, SCNHM VAF 12 (Appendix A, Figure A.8), was found in a very similar lithofacies as SCNHM VAF 4 (Figure 4.11). This specimen is roughly three times larger than SCNHM VAF 4. The majority of the original bone of this specimen has weathered away due to modern processes. What bone remains is coated in a calcite rind and exhibits blocky, irregular breakage. A few undamaged bone elements (i.e. the left radioulna) exhibit no signs of pre-burial, subaerial weathering or abrasion. Where many of the elements have been eroded away, there are moderately defined molds. The right arm, leg, and illium are missing as a result of natural breakage of the rock containing the specimen. Like SCNHM VAF 4, SCNHM VAF 12 was found in close association with abundant ostracods and mollusks.

Unlike SCNHM VAF 4 &12, SCNHM VAF 5 (Appendix A, Figure A.9) is a mold with only a few remnants of the calcite rind which was found surrounding elements in the other two specimens. Further, SCNHM VAF 5 is represented by the mold of the cranium and presacral vertebrae. The right appendicular elements may be preserved in the matrix of the specimen, but they have not been mechanically exposed due to their fragile nature. The left appendicular elements and pelvic girdle are missing as a result of a natural break in the rock.

SCNHM VAF 2 is found in the same lithofacies as SCNHM VAF 4, 5 & 12. The primary difference between this specimen and the others is that this block contains one or more completely disarticulated individual(s). SCNHM 2 is a jumble of closely associated elements. When elements are recognizable, they seem to be intact, with no pre-burial weathering or abrasion. There does not seem to be any winnowing of less dense or mobile elements (cf. Voorhies, 1969). The only damage to bone elements is irregular, blocky breakage and modern weathering. As in the specimens described above, calcite rinds occur on many elements, and bone elements are closely associated with abundant ostracods and mollusks.

The fossiliferous calcareous siltstone and fine-grained sandstone within Member C has irregular bedding and, unlike the previous lithofacies, there are no associated ostracods or mollusks. Bone elements preserved in this lithofacies are completely disarticulated and do not appear to be definitively associated with one another. Typified by SCNHM VAF 11 (Figure 4.12), SCNHM VAF 18 (Appendix A, Figure A.10) & 19 and a number of other specimens that carry SCNHM field number 2278, bones show no

signs of pre-burial, subaerial weathering. Where articular ends are present they show no signs of abrasion. Most specimens appear to have been complete at the time of burial,
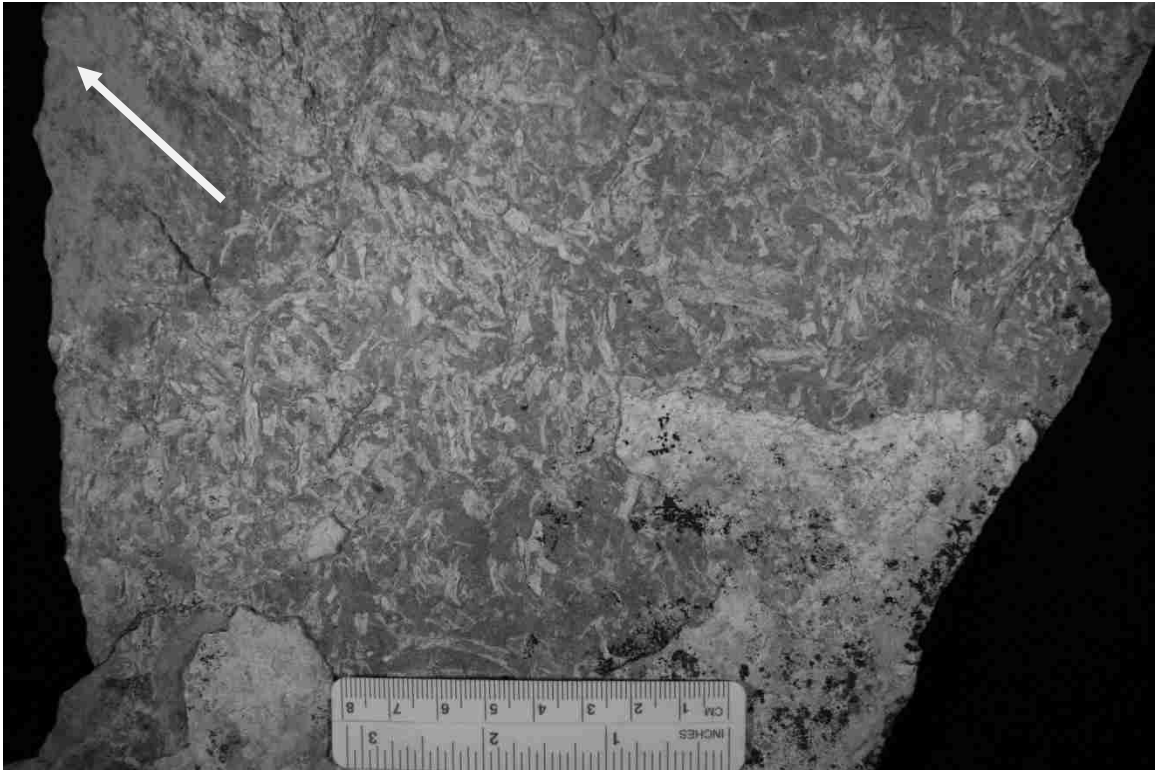
Figure 4.12. A sample of the frog bone bed (SCNHM VAF 11) from field site 2278. All of the lighter colored items are frog bones in a darker, very-fine-to-fine, massive sandstone. The prominent white surface beneath and adjacent to the scale bar is a calcite rind. Notice the chaotic distribution of elements. Using an arbitrary north on this sample of float, the orientation of 27 bones was measured (see Figure 4.13). The arbitrary north direction is indicated.

with a few exceptions. All specimens from SCNHM field site 2278 were collected as float, so orientation of the original specimens could not be determined. Using an arbitrary north, paleocurrent analysis was conducted on long bone elements within one bone-rich specimen (Figure 4.12). The resulting rose diagram (Figure 4.13) shows no strong preferred orientation of long-bone elements within this horizon, although there is a weak north-south orientation. The elements range in size from approximately 3 mm (vertebrae and phalanges) to 21 mm (ilia). Bones are commonly superimposed upon one another,

with bone-on-bone contacts. This lithofacies is laterally extensive for hundreds of

meters; it is variable in thickness as well as lithology, varying between silt and fine-

grained sandstone. The base of this unit does not possess scour marks or any other signs

of erosional processes. Further, this bed does not contain any internal or surficial

sedimentary structures, and appears massive. This lithofacies is observed in only a single

horizon within Member C.
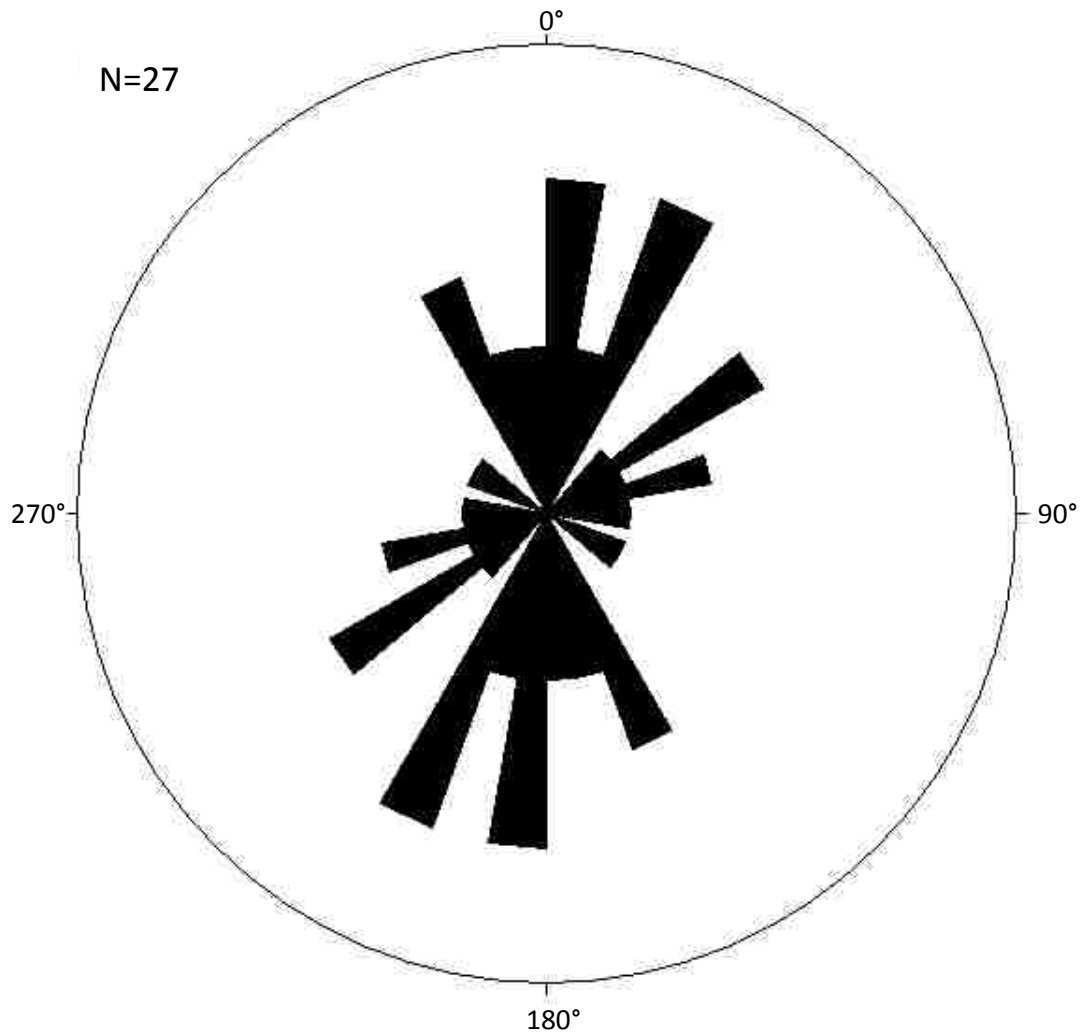
Figure 4.13. Rose diagram of 27 long bone elements in the frog bone bed of Member C, oriented to an arbitrary north. This sample was collected as float. There is no visibly apparent, strongly preferred orientation of long-bone elements, although there is a weak north-south orientation. The average of the right hemisphere is 76.2° with a 1σ of 60°.

Member C Taphonomy

Member C differs from Member B in that invertebrate remains are found within the same lithofacies and with similar preservation as vertebrates. The first taphonomic mode consists of frogs, ostracods, and bivalves occurring together within horizontally laminated, calcareous siltstone. Ostracods in Member C do not show signs of "swarming" (in contrast to Member B), and bivalves are fully articulated, unlike those in the tempestite beds in Member B. Ostracod density seems rather uniform, whereas bivalve density is variable. This depositional environment of the horizontally-laminated, calcareous siltstone lithofacies is interpreted to be a lacustrine delta (Druschke, 2010). As in the case of Member B, the ostracod and bivalve taxa indicate an alkaline pH (Good, 1987; Swain, 1987). Similar to Member B, frogs from this taphonomic mode are found nearly fully articulated in life position. This suggests that the frogs were subjected to minimal transport and scavenging. The well preserved "life posture" of these frogs is also similar to Member B in requiring the body to settle to the bottom within three weeks (Dodson, 1973); bloating and disarticulation were retarded, presumably due to low water temperature (Elder, 1985). Given that Member C is interpreted to be a delta environment, the laminae of the siltstones are not varves. The high degree of articulation of the frogs, as in Member B, is likely the product of attritional accumulation through time. A low-energy environment is supported by the presence of articulated bivalves (Good, 1987).

The second taphonomic mode of Member C is odd, in that frogs are the only preserved organisms; invertebrates are completely lacking. Given that none of the frog elements displays evidence of subaerial weathering, I suggest that they were not exposed

to air and light for any significant amount of time. Furthermore, no signs of abrasion are present, which supports the interpretation of minimal transport distance. The bones show no strongly preferred orientation, which eliminates the presence of unidirectional or bidirectional fluid flow. The presence of bones of a wide array of sizes in a poorly-sorted matrix supports the conclusion that these elements were deposited in a single depositional event, such as a sediment-gravity flow. Other aspects of this unit which support a sediment gravity flow interpretation include the massive nature of the host bed, as well as lateral variability in bed thickness. Another interesting observation is that many elements occur in a bone-to-bone contact relationship, meaning that the bones were likely without flesh prior to burial. There are no observable articulations or close associations, suggesting that the animals were disarticulated when they became entrained within the sediment-gravity flow.

Actualistic studies of frog and toad carcasses in pond water show that frogs can begin disarticulating within 21 days, but they remain mostly articulated for up to 45 days (Dodson, 1973). Therefore the depositional event was not likely the culprit in killing the organisms; they were already dead and in the catchment before the event. There are no tell-tale signs of scavenging of elements, such as green-stick fractures or tooth marks. Mass die-offs of anurans are known to occur today (i.e., Lips, 1999; Rachowicz et al., 2006) and have been invoked in other prehistoric instances (Henrici & Fiorillo, 1993). Given the wide range of element sizes and random orientation of elements, I interpret this taphonomic mode to be a non-selective event assemblage. Henrici & Fiorillo (1993) attribute a dense accumulation of frogs in a nearshore environment to lake fetch; here I

propose that in this instance the frogs were already dead, and that the concentrating

mechanism was sedimentary, in the form of a sediment-gravity flow.

Discussion

Of key significance in this study is the documentation of a prehistoric highland

biota. High elevation is inferred from previous studies (Coney and Harms, 1984; Jones et

al., 1998; Dilek and Moores, 1999, DeCelles, 2004), and supported in this study. This

example also provides for an instance in which taphonomy complements the inferred

geological setting. The preservation of frogs that apparently did not bloat and float due to

cool water temperatures, which lived roughly during the time of the Paleocene-Eocene

Thermal Maximum, when global temperatures were unusually warm (Zachos et al.,

2001), can easily be explained by invoking high altitude (Snell, 2011). Further support

for the Sheep Pass basin being a cool-water basin is found in Good's (1987) work, in

which he looked for a modern analog for the *Valvata, Hydrobia*, Sphaerirrdae-mollusk

association found in the Sheep Pass Formation. He mentions that, based upon

palynological data, the Rocky Mountain region is interpreted to have been tropical to sub-

tropical during the time of Sheep Pass Formation deposition. He inquired about mollusk

assemblages of tropical and sub-tropical regions today, but he found no analog (Good,

1987). It was when he looked at more temperate, cooler water lakes that he found

modern analogs to the Sheep Pass Formation mollusks (Good, 1987).

A puzzling aspect of the paleontology of the type section of the Sheep Pass

Formation is that no vertebrates except frogs have been found, including such aquatic and

semi-aquatic groups as fish, turtles, crocodilians, or water fowl. In other localities there

is a diverse mammalian fauna known from younger portions of the Sheep Pass Formation

(Emry & Korth, 1989; Emry, 1990), however in Sheep Pass Canyon the only vertebrates are frogs, despite the presence of a diverse invertebrate fauna.

As a result of this study, other researchers looking for ancient high-elevation biotic records will likely see sedimentary units represented by a combination of lacustrine, debris-flow, and minor fluvial components as a result of complex topography. It may also be observed that many modern montane basins are in fact lake basins. The Sheep Pass Formation can serve as a model for taphonomic modes one might expect to find in other similar environments.

Conclusions

The Sheep Pass Formation type section, spanning from the Maastrichtian to the Eocene, represents a highland lacustrine setting on the Nevadaplano of east-central Nevada. This section preserves an abundant invertebrate fauna of gastropods, bivalves, and crustaceans. This section also preserves exceptionally abundant and well preserved, though not taxonomically diverse, frog remains, the majority of which were preserved as a result of attritional processes in an environment conducive to rapid settling and lack of bloat-and-float conditions. Two settings are the exception, reworked elements in presumed tempestite beds of Member B, and a sediment-gravity-flow deposit which entrained a number of already dead individual frogs and concentrated them in a single massive bed within Member C. These taphonomic modes (summarized in Table 4.1) may help in formulating a model of other high-elevation biotas and the preservation of biological remains into the rock record. Since the previous interpretations of a high elevation plateau are supported by taphonomic modes of the Sheep Pass Formation, the null hypothesis of the Willow Tank Formation, Newark Canyon Formation and the Sheep

Pass Formation all being deposited at approximately the same elevation is rejected, and

the alternative hypothesis is supported (configuration B of figure 1.3).

Table 4.1 Paleontology and taphonomic modes of the Sheep Pass Formation

Lithofacies	Plants & Inverts	Frogs	Depo. Environment
Member B			
Dolomitic clayshale	Plant impressions, no animal body or trace fossils	No frogs	Shallow lacustrine with emergent veg.
Crinkle-fabric, irregularly-laminated, dolomitic mudstone	Allochthonous leaves, abundant invertebrate trace fossils	Abundant, articulated frogs	Shallow, lacustrine, microbial mats
Planar-laminated, dolomitic mudstone	Abundant invertebrate body and trace fossils. No plants	Abundant, articulated and associated frogs	Low-energy lacustrine
Irregularly bedded mudstone with common mud rip-up clasts	Abundant articulated and disarticulated bivalves	Isolated elements	Tempestites
Member C			
Horizontally-laminated, calcareous siltstone	Abundant, articulated bivalves and ostracods. No plants	Common, articulated frogs.	Lacustrine delta
Massive, irregular bed of varying grain-size and element density	No plants or inverts	Abundant, disarticulated frog elements	Sediment gravity flow

CHAPTER 5

SUMMARY

This study examined three Cretaceous to Paleogene formations interpreted to be the deposits of different tectonic settings of the Sevier orogeny. These studies were done to test the hypothesis that the biota and preservational modes of organisms from these units could predict whether the Sevier hinterland was deposited at the same elevation as the foreland. An alternative hypothesis was that the different tectonic settings would preserve basin-fill deposited all at different elevations (Chapter 1).

The first study, of plant remains preserved in volcaniclastic units of the Cenomanian Willow Tank Formation, suggest that the foredeep of the Sevier foreland in southern Nevada during mid-Cretaceous time was deposited at a similar elevation as other contemporaneous units from the northern Rocky Mountain region of North America. The presence of *Magnolia* and entire marginated leaflets of *Sapindopis magnifolia* support the interpretation that southern Nevada may have been warmer than the northern Rocky Mountain region during mid-Cretaceous time. This study was not instructive as to determining the elevation of deposits of the Sevier hinterland.

The second study focused on the exposures of the Aptian Newark Canyon Formation from east-central Nevada. Preservational modes as well as the presence of geographically and climatically sensitive taxa, hybodont sharks and the turtle Glyptops, all in common with contemporaneous deposits of the Sevier foreland Cedar Mountain Formation all support the configuration of the null hypothesis during Aptian time for central Nevada.

The final study focused on the Maastrichtian-Eocene Sheep Pass Formation of east-central Nevada. Taphonomic investigations of preservational modes of this unit, in

addition to previous paleoaltimetry studies (Snell, 2011) support previous interpretations that these deposits represent a high elevation setting (Coney and Harms, 1984; Jones et al., 1998; Dilek and Moores, 1999, DeCelles, 2004). Thus the Sheep Pass Formation does not support the null hypothesis, but is in line with the configuration of the alternative hypothesis (Figure 1.3).

Although the Willow Tank Formation was not instructive in determining the relative elevation of the Sevier hinterland, the biota was instructive in placing the unit into a paleogeographic setting in relation to contemporaneous floras. The Newark Canyon Formation biota and their preservational modes are all consistent with a relatively low elevation which suggests that the Nevadaplano did not uplift until post-Aptian time (Figure 5.1). The preservation of organisms in the Sheep Pass Formation supports a high elevation setting for this unit, implying that uplift had occurred pre-Maastrichtian time (Figure 5.1), but post-Aptian time in central Nevada.
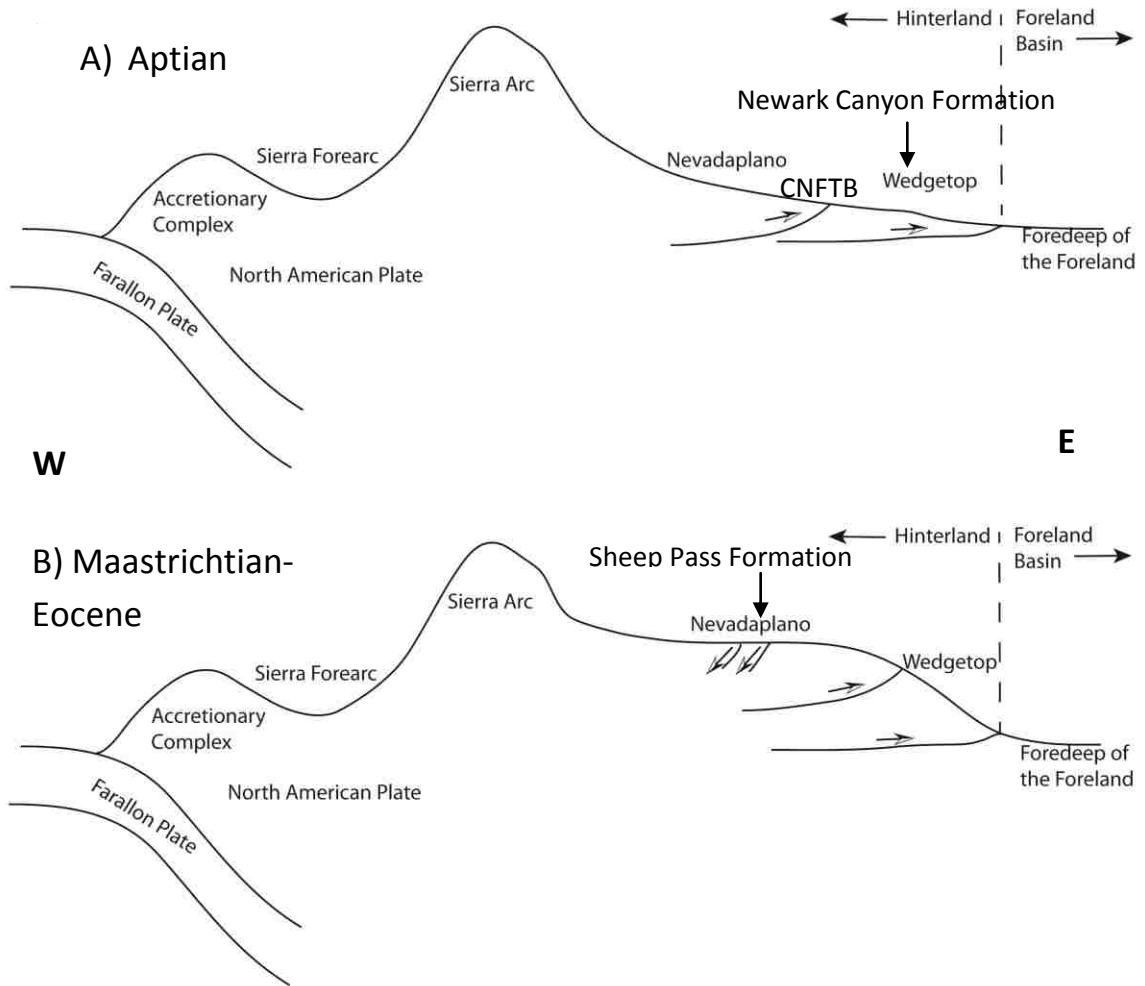
Figure 5.1. A) Represents the configuration of the null hypothesis. Deposits of the Newark Canyon Formation are consistent with being deposited at low elevation based on the biota preserved within exposures of the unit. The wedge-top was low lying. B) Represents the configuration of the proposed alternative hypothesis. The preservation of biotic remains in the Sheep Pass Formation is consistent with being deposited in a high elevation setting. Therefore both hypotheses can be rejected as not fully predicting the geography of the Sevier hinterland. CNFTB-Central Nevada Fold and Thrust Belt.

APPENDIX A

Images of specimens referred to but not figured in text of Chapter 4.

Figure A.1. SCNHM VAF 32A, an impression of a fully articulated frog found in the microbialite mudrock lithofacies.

Figure A.2. SCNHM VAF 31, an impression of an articulated frog, missing the cranium and right arm due to natural breakage of the rock. This specimen is also from the microbialite facies.

Figure A.3. SCNHM VAF 27, a mostly disarticulated but closely associated frog specimen from the planar-laminated dolomitic mudstone lithofacies, with associated ostracods.

Figure A.4. SCNHM VAF 13A, one half of a split slab showing a fully articulated frog specimen from the planar-laminated dolomitic mudstone facies with associated ostracods.

Figure A.5. SCNHM VAF 13B, counterpart to 13A.

Figure A.6. SCNHM 26A, a fully articulated frog specimen from the planar-laminated dolomitic mudstone lithofacies with some associated ostracods. Scale is 1 cm.

Figure A.7. SCNHM VAF 15, represents isolated frog elements in an irregularly bedded lithofacies with mud-rip up clasts (lighter colored blobs) interpreted to be a tempestite.
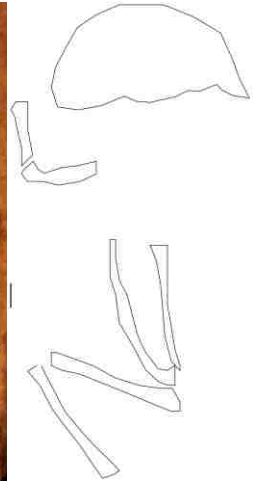
Figure A.8. SCNHM VAF 12, is a large, articulated frog specimen from Member C.

Figure A.9. SCNHM VAF 5, is an articulated vertebral column and cranium. The rest of the specimen is missing due to breakage of the rock or has been obscured by matrix. The small dark specs are ostracods, the larger dark blobs are bivalves.

Figure A.10. SCNHM VAF 18 is a sample of the Member C bonebed. All of the light colored portions are bone elements. Notice the chaotic appearance of the distribution and orientation of elements.

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