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LITHOSTRATIGRAPHY AND FOSSIL AVIFAUNAS OF THE PLEISTOCENE FOSSIL LAKE FORMATION, FOSSIL LAKE, OREGON, AND THE OLIGOCENE ETADUNNA FORMATION, LAKE PALANKARINNA, SOUTH AUSTRALIA

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LITHOSTRATIGRAPHY AND FOSSIL AVIFAUNAS OF THE PLEISTOCENE FOSSIL LAKE FORMATION, FOSSIL LAKE, OREGON, AND THE OLIGOCENE ETADUNNA FORMATION, LAKE PALANKARINNA, SOUTH AUSTRALIA

A DISSERTATION APPROVED FOR THE
CONOCOPHILLIPS SCHOOL OF GEOLOGY AND GEOPHYSICS

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ABSTRACT

Lacustrine sediments of the Pleistocene Fossil Lake Formation of Oregon, and the Oligocene Etadunna Formation of South Australia record packages of upwardly fining sequences that are fossiliferous, including fossil birds. These two paleo-lakes were studied to determine whether stratigraphically collected bird fossils, in conjunction with lithostratigraphy, are a useful tool to infer broad past climatic conditions of ancient lacustrine systems. To do so, depositional environments are inferred from facies analysis of both lake sections and the stratigraphically collected fossil bird bones were identified to the lowest taxonomic group possible, and then grouped into ecologic groups for analysis of changes in abundances and diversity.

The Fossil Lake Formation is divided into four facies; (i) Conglomeratic Sandstone/Siltstone Facies; (ii) Cross-bedded Siltstone Facies; (iii) Siltstone Facies; and (iv) Mudstone Facies. Eight depositional packages were deposited from 646 ka to approximately 10 ka (Martin et al., 2005) as the lake waxed and waned. The facies data suggest the lake experienced periods of gradual deepening followed by abrupt shallowing. The fossil avifauna recovered from the Fossil Lake Formation reveal that shallow-water birds are consistently the most abundant overall. Fossils of diving birds are most abundant in the finer-grained sediments. Geochemically dated tephra dates within the formation allow for correlation to other regional climatic data and the global Marine Isotope Stages. Based on these correlations, the Fossil Lake Formation was primarily deposited during pluvial episodes.

The Etadunna Formation is dominated by siltstone and is divided into three facies: (i) Brecciated and Fossiliferous Siltstone Facies; (ii) Siltstone with Root Traces Facies;

and (iii) Dolomitic Mudstone Facies. Four depositional packages record the rapid in-filling and gradual shallowing of the lake system. Relatively few bird fossils were recovered from the Etadunna Formation and most of the Anseriformes were unavailable for this study. Nevertheless, the fossil avifauna from this study was divided into the same three eco-groups as in the Fossil Lake study. The shallow-water birds were the most abundant, and only a single specimen from the diving bird eco-group has been recovered, suggesting that the lake was likely shallow during most of its history.

As with many fossil collections, inferences made solely from fossil avifauna may be limited, because of sample size or taphonomic biases. However, stratigraphic collections of avifauna can be combined with other datasets, such as lithologic data, to better construct broad past paleoenvironmental conditions, such as water depth. In this study, the fossil avifauna of both formations are in agreement with the interpreted depositional environments.

CHAPTER 1: LITHOSTRATIGRAPHIC SIMILARITY OF THE FOSSIL LAKE FORMATION, FOSSIL LAKE, OREGON, AND THE ETADUNNA FORMATION, LAKE PALANKARINNA, SOUTH AUSTRALIA

1.1: INTRODUCTION

Lacustrine deposits often serve as detailed records of regional geologic history. Lake sediments contain physical, chemical, and biological variables that reflect climatic and depositional changes that can reveal the geologic history of the lake. Two examples of ancient lacustrine deposits that contain such data are the Pleistocene Fossil Lake Formation of Oregon (646-10 ka), and the Oligocene Etadunna Formation of South Australia (24-26 Ma). The stratigraphy of both formations consists of packages of upwardly fining sequences, which have been interpreted as the result of the waxing and waning of the water levels in the respective paleo-lakes (e.g. Stirton et al., 1961; Allison, 1979). Although the general lithology of both formations has been published (Stirton et al., 1961; Martin et al., 2005), detailed paleoenvironmental reconstructions based on facies analysis had not been determined.

Both the Fossil Lake Formation and the Etadunna Formation are important fossil localities that have been extensively collected since 1876 and 1953, respectively. Fossils from both areas include fish, birds, and large and small mammals. More recently, the fossils have been stratigraphically collected, allowing for the study of paleofaunal changes through geologic time. Although the mammalian paleofauna has been previously studied and the results have been published (e.g. Fossil Lake: Elftman, 1931; Martin, 1996, 2006; Etadunna: Stirton et al., 1968; Woodburne et al., 1993), the abundant, well preserved bird fossils of both formations have remained largely unstudied.

The main goal of my study was to determine whether stratigraphically collected bird fossils, in conjunction with lithostratigraphy, are a useful tool to infer past paleoenvironmental and paleoclimatic conditions of ancient lacustrine systems. The stratigraphy of each formation was divided into facies that were analyzed to determine depositional environments. The individual facies were grouped into packages that represent temporal changes in water depths of the lake systems. The identified bird families are classified into the following eco-groups: diving birds, shallow-water birds, or terrestrial birds in order to relate to the depositional environments and to allow for comparisons of temporal changes in abundances and diversity. The diversity of each eco-group represented in each facies is evaluated in an effort to determine temporal changes and evaluate the changes in regard to depositional environments. Determination of facies, depositional environments, and changes in abundances and occurrences of the Fossil Lake Formation and the Etadunna Formation are discussed in Chapters 2 and 3, respectively. A summary of the effectiveness of fossil avifauna and recommendations for further work is found in Chapter 4.

1.2: METHODS OF STUDY

To better understand the changes in the lake levels, as well as the relationships between fossil localities, stratigraphic sections were trenched and measured, noting changes in lithology and the variations in sedimentary structures. Because of the nearly horizontal dip of the beds and the subdued topography, neither formation is exposed in its entirety at a single location. Therefore, several stratigraphic sections were trenched, described, and correlated throughout each basin. Samples were collected and brought to the University of Oklahoma for petrographic and grain-size analyses. Samples were taken at different intervals, ranging from a 10-cm scale to single representative samples from certain lithologic units. Composite stratigraphic columns detailing the lithology, grain size, sedimentary structures, and unit thicknesses were produced from the individual sections. Color determinations were made using the Munsell Rock Color Chart.

Grain-size analyses were performed on collected samples, as they were generally poorly consolidated. Samples were lightly crushed and approximately 1 g of homogenized subsample was placed in vials of distilled water with two to three drops of sodium metaphosphate to disaggregate and deflocculate the clays; the vials were then sonicated for 15 minutes. Just prior to grain size analysis, each sample was thoroughly mixed and a small aliquot was taken by pipette and introduced into a Beckman Coulter LS Particle Size Analyzer, LS v.3.29 with a small-volume module and analyzed using a Fraunhofer optical model.

Smear slides were also made from the above samples. A small amount of sediment and water was smeared onto a glass slide and put into an oven to dry. A cover slide was then glued onto the sample using Norland Optical Adhesive. A binocular microscope was employed to determine composition of the sediment samples was completed.

Previous collections of the Fossil Lake specimens are biased toward larger specimens based on collecting methods that were not as rigorous as current methods. Recent collections made by the South Dakota School of Mines and Technology are more representative of the complete assemblage. Fossils are collected by members of the field crew walking side by side (Figure 1.1) or by crawling (Figure 1.2) at localities, allowing for both large and small specimens to be collected. Fossil collection at Lake Palankarinna was conducted in a similar manner.

Fieldwork for my research at Fossil Lake was conducted for two weeks per year for the years 2003-2008, during which thousands of fossil specimens were collected. Fieldwork for the Etadunna Formation was conducted over a total of ten days in 2005 and 2007.

The bird fossils that have been stratigraphically collected from the Fossil Lake Formation are housed in the Museum of Geology at the South Dakota School of Mines and Technology (SDSM) in Rapid City, South Dakota. The South Australian specimens are housed at the South Australia Museum (SAM) in Adelaide, South Australia, and the University of California Museum of Paleontology (UCMP) in Berkeley, California. Unidentified specimens that have been collected more recently have been loaned to the author by both SDSM and UCMP. The extensive avian osteology collection at the Sam Noble Oklahoma Museum of Natural History (SNOMNH) of the University of Oklahoma, Norman, Oklahoma, was used as comparison for identification of the fossils.

Figure 1.1: Members of a field crew collecting fossils by walking in lines.

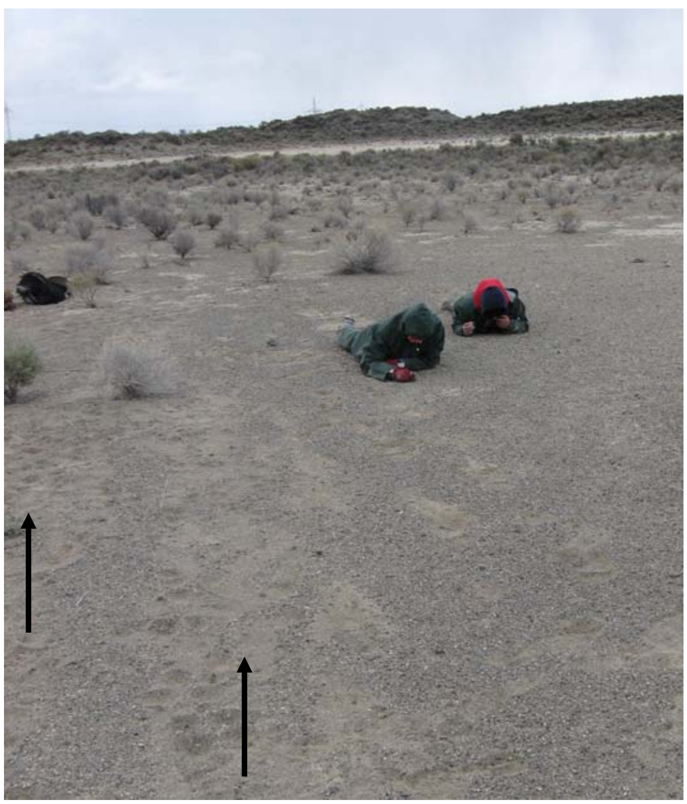


Figure 1.2: Members of a field crew collecting fossils by crawling. Completed crawl lines are indicated by arrows in the left part of the picture. Crawling ensures the collection of small fossils.

CHAPTER 2: LITHOSTRATIGRAPHY AND FOSSIL AVIFAUNA OF THE PLEISTOCENE FOSSIL LAKE FORMATION, FOSSIL LAKE, OREGON

2.1: INTRODUCTION

The Pleistocene Fossil Lake Formation of south-central Oregon was first described in 1926 (Smith and Young) and represents deposition in a pluvial lacustrine system (Allison, 1979), which serves as an archive for the geologic, climatic, and biologic histories of the area. The stratigraphy preserves rhythmic deposition that resulted from glacial and interglacial intervals (Allison, 1979; Martin et al., 2005). The Fossil Lake Formation was deposited from 646-10 ka as a part of the larger, pluvial Fort Rock Lake (Allison, 1979; Martin et al., 2005). These dates are based on geochemical correlation of tephra layers, as well as radiocarbon dates from fossils (Allison, 1979; Martin and Kihm, 2003; Martin et al., 2005; Martin, 2006).

The Fossil Lake area is a significant Pleistocene fossil locality and yields numerous vertebrate fossils. Fossil birds are quite common but have not been studied in a stratigraphic context. Early studies of the avifauna noted ducks, grebes, rails, grouse, gulls, pelicans, storks, falcons, hawks, songbirds, and owls (Shufeldt, 1891, 1913; Miller, 1911; Howard, 1946).

The goals of this part of the study were two-fold: 1) to develop a depositional model for the observed stratigraphic packages in the Fossil Lake Formation, and 2) to produce an avifaunal list through the identification of the bird fossils that is stratigraphically tied to these depositional packages. Based on previous regional climatic studies and the derived tephra-based chronology (Martin et al., 2005) tied to the marine isotope stages, I can correlate global and regional climatic events to the Fossil Lake Formation. The facies and fossil data can then be placed into this framework to determine how the climate affected both the depositional environments and the fossil avifauna of the lake system.

2.2: LOCATION OF STUDY AREA

The Fossil Lake study area is located in Lake County, Oregon, 480 km southeast of Portland. The study area is part of the larger pluvial Fort Rock Lake that covered approximately 1200 km^2 (Snyder et al., 1964; Allison, 1966, 1979; Martin et al., 2005) with a maximum paleo-water depth of over 60 m (Allison, 1966).

Figure 2.1 details the general location of Fossil Lake. The dark line signifies the maximum extent of Fort Rock Lake. Today, the area is part of the High Plains Desert covering over 2,650 ha (Snyder et al., 1964). Active dune fields border Fossil Lake on the northeastern side. Water can fill a small portion of the basin during rainy years, (Allison, 1966), but the region is generally dry, with an average of approximately 25 cm of precipitation per year (Allison, 1979).

2.3: GEOLOGICAL SETTING

The Fort Rock Lake Basin is divided into three sub-basins: Fort Rock Basin to the west, the Christmas Valley Basin to the east, and the Silver Lake Basin to the southwest. Fossil Lake is located within the Christmas Valley Basin. Fort Rock Lake Basin is situated between the Basin and Range Province to the south and the Columbia Intermontane Province to the north (Snyder et al., 1944; Allison, 1979). Numerous basins exist in the south-central portion of Oregon as a result of Cenozoic extensional faulting in the region (Allison, 1979; Martin et al., 2005), with Fort Rock Lake being the most northern pluvial lake basin in the area (Allison, 1979).

The Newberry Volcanic Complex lies northwest of Fossil Lake and Crater Lake (Mt. Mazama) lies to its west. Both are sources for the tephras found within the Fossil Lake Formation that allow for age constraints and correlation within the Fossil Lake Formation as well as with nearby basins (Kuehn and Foit, 2001).

The regional climate during deposition of the Fossil Lake Formation fluctuated during and between glacial and interglacial conditions (Allison, 1979; Martin et al., 2005). Tephra dates recovered from the formation allow for correlation with the known marine isotope stages and the North American glacial stages.

2.4: PREVIOUS WORK

The geology of the Fossil Lake area was first described by Russell (1884) and most recently by Martin et al. (2005). Allison (1979) discussed the numerous lacustrine features in the ancient lake basin, including shoreline features and wave-cut terraces.

The overall stratigraphy of the Fossil Lake Formation consists of eight packages of repetitive, upwardly fining sequences: from a basal basalt-pebble conglomerate, to red or brown sandstone, to siltstone, and capped by a mudstone. At least three significant unconformities exist within the deposits (Martin et al., 2005). Five of the eight packages contain a tephra (Martin and Kihm, 2003; Martin et al., 2005).

Fossils have been collected from Fossil Lake since 1876, when discovered by Governor Whiteaker of Oregon (McCornack, 1920). For several years following the initial discovery of fossils, many scientific collections were made, including those by Thomas Condon, Charles H. Sternberg, Edward D. Cope, Israel Russell, William Day, Annie M. Alexander, Chester Stock, and E.L. Furlong. Cope (1878) was the first to publish on the fossil birds but eventually gave the collection to R.W. Shufeldt for further study. Shufeldt studied the Cope and Condon collections and published his first paper in 1891. L. Miller took over the study of the University of California specimens that were collected by Alexander and published his findings in 1911. Howard (1946) summarized the history of the collections to date. In 1989, J.E. Martin from the South Dakota School of Mines and Technology (SDSM) began a new collection of fossils that are stratigraphically collected. My study focused on part of the SDSM collection because the corresponding stratigraphic data allow for integration of the fossil and stratigraphic datasets.

2.5: LITHOSTRATIGRAPHY

The present topography of Fossil Lake lacks significant areas of outcrop and relief is very subtle. Few lithologic units are exposed at any given site and the topography follows the lithology. Although the stratigraphic section is composed of deposits that often look similar, interbedded tephras are useful in determining stratigraphic position. Each package is an association of two facies; the basal facies is composed of conglomeratic sandstone/siltstone, and the overlying facies is either a siltstone or mudstone. The base of each package is commonly scoured. The general stratigraphy of the Fossil Lake Formation has been published by Martin et al. (2005), who described and divided the formation into 18 units.

In this study, several stratigraphic sections were trenched, measured, and described throughout the Fossil Lake Basin in an effort to better understand the depositional history of the lake and the associations among fossil localities. Individual and correlated sections are presented in Figures 2.2-2.6. The sections were measured at protected fossil localities and, therefore, exact location data are not being disclosed. However, detailed locality data are on file at the Museum of Geology at SDSM and are available to qualified investigators upon request. The individual units of the Fossil Lake Formation can be classified into one of four facies and are described in Table 2.1. Facies determination was primarily based on grain size, color, and the presence ofrabsence of diagnostic sedimentary structures; the grain-size data are presented in Appendix 1. Thicknesses of the individual facies vary and average thicknesses are illustrated in the composite stratigraphic column in Figure 2.7. In Figure 2.7, the unit numbers correspond to units defined in Martin et al. (2005), and in some cases his units were combined into a single facies. The following is a description of the four facies:

Conglomeratic Sandstone/Siltstone Facies (CSF):

Description: This facies is a conglomeratic sandstone/siltstone with an average thickness of 0.40 m. The lower contact is sharp to scoured. The upper contact is typically gradational into the overlying siltstone or mudstone. Grain size of the conglomeratic matrix varies from fine sandstone to fine siltstone. Color varies from moderate yellow brown (Munsell color 10YR 5/4) to light olive gray (5Y 5/2). The conglomeratic clasts consist of basalt gravels, pumice clasts, and tephra. Basal lags containing small, vesicular, rounded, basalt gravels that range from 1-5 cm, with the smaller size fraction being more common, occur locally. Otherwise, the gravel fraction

(30%) is suspended in matrix (70%). The basalt gravel lags are more common in the lower part of the section (Packages 2 and 3, see below), whereas basalt gravels suspended in the sandstone/siltstone matrix more commonly occur in the upper part of the section (Packages 4-7, see below). Local tephra layers, however, are clast supported. This facies is laterally widespread and contains numerous disarticulated cyprinid fish fossils.

Interpretation: This facies represents deposition at or near a shoreline, as inferred by the coarse grain size and the interbedded gravels, which could represent wave action that removed the finest fraction (Picard and High, 1981). Although the texture (gravel suspended in matrix) of this facies is similar to that of debris flows or fluvial deposits, the lateral continuity of the facies and the presence of fossil fish make this interpretation unlikely. The facies grades into the overlying facies, either the siltstone facies or the mudstone facies, representing a change from a marginal lacustrine to offshore lacustrine deposition (see below).

Cross-bedded Siltstone Facies (XSF):

Description: This coarse-grained sandstone occurs only once in the section and is 0.65 m thick. Both the upper and lower contacts are sharp. The facies is yellowish brown (10YR 5/2). The base of the facies contains centimeter-scale root traces. The upper part of the facies contains both cross-beds and planar bedding with translatent stratification (Figure 2.8). The cosets are 1-2 cm thick and dip at an angle of approximately 15^{o} to the southeast.

Interpretation: The root traces indicate subaerial exposure. The small scale of the cosets and the translatent stratification are commonly indicative of eolian deposition in the form of wind ripples (Hunter, 1977). Therefore, the facies indicates subaerial deposition in a marginal/palustrine to eolian environment.

Siltstone Facies (SF):

Description: This facies is composed of an average of 0.40 m of siltstone. The lower contacts are gradational from the underlying CSF and the top contacts are sharp and are commonly scoured, and overlain by the CSF. Grain size varies from very fine to fine siltstone and bedding is massive. Color varies from moderate yellow brown (10YR 5/4) to light olive gray (5Y 5/2). This facies lacks sedimentary structures, but contains numerous disarticulated cyprinid fish fossils.

Interpretation: Fossil fish indicate a lacustrine environment. The finer grain size and the lack of basalt gravels indicate deposition away from wave action. Deposition of this facies represents a marginal/shallow offshore lacustrine environment, in which the sediment was thoroughly bioturbated, as evidenced by the massive nature of the facies.

Mudstone Facies (MF):

Description: This facies is a mudstone with an average thickness of 0.45 m. The upper contacts are sharp to scoured and the lower contacts are typically gradational; it is internally massive. Although the grain size data indicates a fine to very fine silt size, the facies is finer-grained than the SF. The grain size data may be biased by incomplete disaggregation of clay particles. This facies is underlain by either the CSF or XSF and is overlain by the CSF. Color varies from pale greenish yellow (10Y 8/2) to yellowish gray (5Y 7/2). This facies contains numerous cyprinid and salmonid fish fossils. Root traces are locally present at the top of this facies, and are a few centimeters long.

Interpretation: The bulk of the facies formed in an offshore lacustrine environment, as indicated by the fine grain size and the presence of cyprinid and salmonid fish. The root traces locally present occur at the top of the facies and indicate an abrupt drop in lake level and subaerial exposure, likely in a palustrine setting.

Facies Associations

Analysis of the vertical stacking of facies allow for designation of eight packages, as defined above. The following describes the facies association for each of these eight packages defined within the Fossil Lake strata. Tephra dates used herein are summarized in Martin et al. (2005). Table 2.2 details the stratigraphic position, correlated tephra, and date of each of the Fossil Lake Formation tephras.

Package 1: Mudstone Facies

It is inferred that the base of the studied section probably represents the top of an upwardly fining depositional package; the base of the facies, which is over 1 m thick, was not observed (Martin et al., 2005). The package is capped by tephra A, which has been correlated to the Rye Patch Dam tephra, dated at 646 ka (Williams, 1994). The fine mudstone contains cyprinid fish fossils and represents an offshore lacustrine environment.

Package 2: Conglomeratic Sandstone/Siltstone Facies-Mudstone Facies

This package fines up from the CSF to the MF. The basal CSF contains basalt pebble lags and grades into gray-brown sandstone. The CSF is 0.90 m thick and includes tephra B that has been geochemically correlated to the Dibekulewe tephra dated at 610 ka (Davis, 1978). The facies also contains numerous bird fossils. The top 0.40 m of the package is composed of very fine mudstone that contains cyprinid fish fossils (Fig. 2.8).

The top of the mudstone contains root traces. Package 2 represents a change from marginal (CSF) to offshore lacustrine (base of MF) conditions abruptly replaced by a palustrine environment (top of MF). The package is capped by an unconformity, as evidenced by the juxtaposition of facies, the scoured contact, and the age of the suprajacent tephra.

Package 3: Conglomeratic Sandstone/Siltstone Facies-Siltstone Facies

The base of the CSF fines up from 5-10 cm of basalt-pebble conglomerate to 0.50 m of gray-brown sandstone to 0.35 m of fine siltstone. Tephra C, correlated to the 95 ka Tulelake T64 tephra (Rieck et al., 1992), is interbedded with the siltstone and is shown in Figure 2.9. The CSF contains numerous bird fossils. The base of this package (CSF) was deposited in a marginal lacustrine environment and the top of the package (SF) was deposited in a more offshore lacustrine environment. The package is capped by an unconformity, as evidenced by the juxtaposition of facies and the scoured contact. This package is illustrated in the top part of Figure 2.10.

Packages 4-7: Conglomeratic Sandstone/Siltstone Facies-Siltstone Facies

Each of these four packages begin with approximately 0.30 m of the CSF and grade upward into approximately 0.40 m of the SF. The SF of Package 4 is capped by tephra D, which has been correlated to the 47-ka Marble Bluff Mount St. Helens tephra (Davis, 1985), and by an unconformity, as inferred by the scoured surface and the abrupt lithologic change to the overlying CSF. The SF of Package 7 is shown in Figure 2.11. Package 7 is capped by tephra E, the stratigraphically highest tephra, which has been correlated to the 23.2-ka Trego Hot Springs tephra (Rieck et al., 1992). Tephra E was reworked in water, as indicated by the ripples, as shown in Figure 2.12. Packages 4-7 yield mammal and bird fossils, but these fossils are not as abundant as in the lower packages. Overall, Packages 4-7 appear to represent repetitive changes from marginal to shallow offshore lacustrine environments.

Package 8: Cross-bedded Siltstone Facies-Mudstone Facies

The lower part of the package is 0.65 m of coarse-grained sandstone that contains root traces at the base and cross-beds in the upper portion of the facies. This package is capped with 0.20 m of yellowish gray (5Y 7/2) mudstone that contains numerous salmonid fish skeletons. The bottom of the package represents a marginal to eolian, paludal environment as inferred by the presence of root traces and wind ripples. The lake then filled rapidly to a deeper offshore lacustrine environment, as evidenced by the overlying mudstone with fish fossils. Figure 2.11 depict the Cross-bedded Siltstone facies in outcrop view.

In summary, the depositional packages of the Fossil Lake Formation represent repeated fluctuations in water levels. Each package represents an upwardly fining sequence. Two packages contain root traces, indicating subaerial exposure and likely representing palustrine environments. Tephra layers and/or unconformities mark the upper boundaries of six of the eight packages. Tephra layers mark the top of packages 1, 4, and 7, and unconformities mark the top of packages 2, 3, and 4.

2.6: FOSSIL AVIFAUNA

The Fossil Lake Formation is recognized for the abundance of fossils contained within its sediments. A review of the known and identified fossil birds from all of the previous collections of Fossil Lake material (Cope Collection, Oregon State University

Collection, University of California at Los Angeles Collection, the Condon Collection, the University of California Museum of Paleontology Collection, the California Institute of Technology Collections, and the United States National Museum Collection) was published by Howard (1946). The additions to the avifauna from my study increase the size of the collection and include stratigraphic data, which is advantageous when interpreting the paleoecology of the site. Taxonomic data are organized in stratigraphic order by locality and included in Appendix 2.

The fossil avifauna represented by earlier collecting at Fossil Lake was thoroughly reviewed by Howard (1946), where she deleted synonymous taxa, organized the fossils into families, and counted the minimum number of individuals. The total number of fossil specimens in her study was 2500, which represents 336 individuals, and either 68 or 69 species. The Anseriformes are the most abundant, followed by Podicipediformes, Gaviiformes, Gruiformes, Galliformes, Charadriiformes, Pelecaniformes, Ciconiiformes, Falconiformes, Passeriformes, Strigiformes, and finally Piciformes.

The following is the fossil avifauna from the SDSM collection identified as part of this study. The majority of the fossils are attributed to extant taxa, and the bones are often indistinguishable from modern skeletons. Included with the taxonomic data are ecologic habits of each family and the stratigraphic position and locality that each taxon was recovered from. Table 2.3 compares the faunal lists of Howard (1946) and my study. Her study included more genera, as a result of a larger sample size. However, 13 new taxa are added to the list: the families Gaviidae and Fringillidae; the genera and/or species *Eudocimus ruber*, *Grus* ?*canadensis*, *Charadrius alexandrius*, *Larus occidentalis*, *Falco* sp., ?*Uria* sp., *Otus* ?*kennecotti*, *Cyanocitta cristata*, *Lanius ludovicianus*, ?*Bombycilla cedorum*, and ?*Vireo*. Uncertainty of identification is indicated by "?".

Systematic Paleontology

Class AVES Linnaeus, 1759

Order GALLIFORMES Temminck, 1820

Referred Specimen:

Tibiotarsus: SDSM 28894

Description: The condyles of the distal tibiotarsus are straight and parallel to each other, with a narrow articulation.

Occurrence: Mudstone Facies of Package 2 of site g.

Family PHASIANIDAE Vigors, 1825

Ecology: Phasianidae includes the grouse, which are terrestrial and mostly nonmigratory. Although most are herbivorous, some eat small invertebrates. The family has a diversity of habitats, but the species found in the Fossil Lake Formation inhabits arid environments (Sibley et al., 2001).

Centrocercus urophasianus (Bonaparte, 1827)

Plate 1 A-E

Referred Specimens:

Coracoid: SDSM 30121b

Digit 2, phalanx 1: SDSM 31957

Synsacrum: SDSM 74807

Femur: SDSM 29523

Tibiotarsus: ?SDSM 31958

Tarsometatarsus: SDSM 30177

Description: The coracoid has a robust, curved sternal facet. The synsacrum has a large, saddle-shaped vertebra, and spiky projections. The condyles of the distal tibiotarsus are straight and parallel to each other. The articulation is narrow. The femur has a well defined head and neck. The proximal tarsometatarsus has a prominent intercotylar eminence. The medial condyle of the tarsometatarsus is rounded. The digit 2, phalanx 1 is short and square.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h and cc; Mudstone Facies of Package 2 of site f.

Order ANSERIFORMES Wagler, 1831

Family ANATIDAE Vigors, 1825

Ecology: Ducks and geese mostly herbivorous, migratory water birds that inhabit a wide variety of aquatic habitats, where they breed (Sibley et al., 2001).

Referred Specimens:

Premaxilla: SDSM 28996; SDSM 30082

Description: The premaxilla is flattened and rounded.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites g and h; Conglomeratic Sandstone/Siltstone Facies of Package 4 of site b.

Anas sp. Linnaeus, 1758

Referred Specimens:

Sternum: SDSM 31180

Scapula: SDSM 33048; SDSM 31183

?Coracoid: SDSM 31951

Humerus: SDSM 28276; SDSM 30137

Radius: SDSM 30145

Tibiotarsus: SDSM 74810

Description: The sternum is U-shaped and has a deep coracoidal groove with an external spine. The proximal coracoid is very worn and wide. The scapula has a subrounded glenoid and a pointed and curved acromion. The proximal humerus has a prominent deltoid crest and capital groove. The distal humerus has an oval depression for the brachialis muscle. The radius has a rounded proximal articular surface. The distal end of the tibiotarsus is splayed with a projection on the ventral condyle.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 of sites f and h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b and l.

Anas acuta Linnaeus, 1758

Plate 2 A-B

Referred Specimen:

Ulna: SDSM 74945

Description: The distal end of the ulna is flattened. It is smaller than *A. americana*.

Occurrence: Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f.

Anas americana Gmelin, 1789

Plate 2 C-G; Plate 3 A-E

Referred Specimens:

<u>Basicranium</u>: SDSM 74876

<u>Sternum</u>: SDSM 31179

<u>Coracoid</u>: SDSM 75146; SDSM 33054c; SDSM 31431; SDSM 75466; SDSM 75657a

<u>Scapula</u>: SDSM 30862; SDSM 31182; SDSM 31950; SDSM 74908a; SDSM 74908b; SDSM 74908c; SDSM 30122; SDSM 30123; SDSM 30124; SDSM 30125a; SDSM 30131

<u>Furcula</u>: SDSM 30273

<u>Humerus</u>: SDSM 75572; SDSM 31198; SDSM 74931; SDSM 74933; SDSM 31313

<u>Ulna</u>: SDSM 33056; SDSM 31289; SDSM 31195; SDSM 74945

<u>Carpometacarpus</u>: SDSM 33059; SDSM 31201; SDSM 31277

<u>Femur</u>: SDSM 30164

<u>Tibiotarsus</u>: SDSM 74979a; SDSM 74979b; SDSM 74976; SDSM 30173

<u>Tarsometatarsus</u>: SDSM 31210; SDSM 30281

Description: The sternum has a thin coracoidal groove with a pneumatic fossa distally. The coracoid has a semi-circle shaped facet for articulation with the humerus, and a groove on the acrocoracoid process, as well as ridges in the bone surface. The scapula has a groove on the humeral facet, a rounded glenoid facet, and has a pointed acromion. The distal end of the furcula has a short bifurcation. The humerus has a curved bicipital crest, a deep capital groove, and the head is undercut. The ulna has rounded dorsal condyle with a long articulation, and a pointed acromion. The extensor process of the carpometacarpus is square. The pisiform process is sharp and points forward. The femur has robust, rounded condyles. The supratendinal bridge of the tibiotarsus angles toward the medial condyle. The tarsometatarsus is concave proximally and the calcaneal ridge continues downshaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, f, and h; Mudstone Facies of Package 2 of sites b, f, and c; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites i and f; Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b and h.

Anas clypeata Linnaeus, 1758

Plate 4 A-F

Referred Specimens:

Coracoid: SDSM 30109

Scapula: SDSM 30587

Ulna: SDSM 31196; SDSM 32969

Carpometacarpus: SDSM 33058; SDSM 31291; SDSM 28887; SDSM 30167; SDSM 30275

Radius: SDSM 30562a; SDSM 30562b

Tibiotarsus: SDSM 30880

Description: The coracoid has a well developed facet for articulation with the humerus. The scapula has a well developed glenoid facet, and a pointed acromion. The ulna has a rounded dorsal condyle with the articulation continuing along the shaft with a flattened distal end. The distal radius is rounded and square with a well developed ligamental prominence. The carpometacarpus has a sharp alular process and the pisiform process points forward with an intratrochlear fossa. The extensor process is rounded and the minor metacarpal is broken and missing. The tibiotarsus has a narrow distal end and the medial condyle is angled away from the shaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, and h; Mudstone Facies of Package 2 of sites b and g; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b, f, and h.

Anas crecca Linnaeus, 1758

Plate 5 A-F

Referred Specimens:

<u>Coracoid</u>: SDSM 30859; SDSM 31184; SDSM 31189; SDSM 30117; SDSM 30119; SDSM 74802; SDSM 28269

<u>Scapula</u>: SDSM 30125b

<u>Humerus</u>: SDSM 74930; SDSM 29139; SDSM 30135; SDSM 30139; SDSM 30141; SDSM 28418

<u>Ulna</u>: SDSM 31194; SDSM 31197; SDSM 29148; SDSM 30151

<u>Carpometacarpus</u>: SDSM 74947; SDSM 30276

Tarsometatarsus: SDSM 30567

Description: The coracoid has a well developed facet for articulation with the humerus; a deep, well rounded scapular cotyla; and a thin shaft. The scapula has a flat gelnoid facet and a pointed acromion. The proximal humerus has a deep capital groove, a deep pneumatic fossa, and a prominent, thin deltoid crest. The dorsal condyle of the humerus is curved and sharp, and the depression for the brachialis muscle is well developed. The ulna has a rounded conyle that extends up the shaft. The carpometacarpus has a blunt extensor process. The tarsometatarsus has a square shaft. Trochlea II is rounded. Trochlea III extends past II and IV.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, g, and h; Mudstone Facies of Package 2 of sites b, and h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone facies of Package 3 of sites b, h and l.

Anas platyrhynchos Linnaeus, 1758

Plate 6 A-F; Plate 7 A-D

Referred Specimens:

Sternum: SDSM 74905; SDSM 32965

Coracoid: SDSM 75501; SDSM 33052; SDSM 33053a; SDSM 33053b; SDSM 33054a; SDSM 33054b; SDSM 33049; SDSM 31288; SDSM 75813; SDSM 31191c; SDSM 29122; SDSM 30115; SDSM 30116; SDSM 30121a; SDSM 29958; SDSM 74801

Scapula: SDSM 30863; SDSM 31325

Furcula: SDSM 30272

Humerus: SDSM 30869; SDSM 30872; SDSM 31199; SDSM 74929; SDSM 29145; SDSM 75138

Ulna: SDSM 30564; SDSM 30155

Radius: SDSM 30561; SDSM 75512; SDSM 30144; SDSM 30147

Carpometacarpus: SDSM 74818

Synsacrum: ?SDSM 31203; SDSM 74954; SDSM 74958; SDSM 74959; SDSM 30159; SDSM 75665

Tibiotarsus: SDSM 29189a; SDSM 29189b; SDSM 30172; SDSM 30176; SDSM 74809; SDSM 74820

Tarsometatarsus: SDSM 75171; SDSM 74989a; SDSM 74989b; SDSM 30179

Description: The coracoid has a well developed sternal facet and ridges on the bone surface. The sternum is rounded and has a ventral spine. The scapula has a triangular glenoid and a pointed acromion. The humerus has a curved dorsal condyle, a well developed attachment for the brachialis muscle, and a deep olecranon fossa. The ulna has a well developed olecranon and the cotyles are elongate. The proximal radius has a hollow ulnar facet and a well developed tendon groove. The extensor process of the carpometacarpus is blunt and angled up. The medial condyle of tibiotarsus is angled medially, and has a well developed fibular crest. The synsacrum has broad, perpendicular processes. The tarsometatarsus has a rounded trochlea II and a square shaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, g, and h; Mudstone Facies of Package 2 of sites b, h, and j; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites e, f, and i; Conglomeratic

Sandstone/Siltstone Facies of Package 3 of sites b, f, h, and q; Siltstone Facies of Package 3 of site b.

Aythya affinis (Eyton, 1838)

Plate 8 A-B

Referred Specimens:

Tarsometatarsus: SDSM 31326

Synsacrum: SDSM 33065

Description: The tarsometatarsus has a rounded trochlea II and a square shaft. The bone is smaller than in *A. platyrhynchos*. The synsacrum has a rounded, saddle-shaped vertebral body.

Occurrence: Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site q.

Branta sp. Scopoli, 1769

Referred Specimens:

Sternum: SDSM 75143; SDSM 74904:

Coracoid: SDSM 33050; SDSM 30121c; SDSM 74917; SDSM 74915

Scapula: SDSM 30916; SDSM 28612

Furcula: SDSM 74903a; SDSM 74903b;

Ulna: SDSM 30588; SDSM 75003

Associated radius/ulna: SDSM 75505

Radius: SDSM 31955

Digit 2, phalanx 1: SDSM 33060

Synsacrum: SDSM 30158

Tarsometatarsus: SDSM 30881; SDSM 30181; SDSM 75672

Description: The sternum has a wide coracoidal groove with a projection at the bottom. The coracoid has a large, flattened facet for articulation with the humerus; a deep, well developed scapular cotyla; and ridges on the surface. The articular surface of the proximal scapula is broken. However, the overall size and shape matches well with *Branta*. The furcula is robust and U-shaped. The ulna has rounded condyles and rounded cotyles. The associated radius and ulna are larger than *B. canadensis*; the ulna includes the proximal end that has well developed cotyla and distal end that has rounded condyles. The radius is slightly bowed with a large ulnar facet. The digit 2, phalanx 1 has a rounded, wide proximal articulation with a raised phlange. The tarsometatarsus has a groove between trochleae III and IV, and trochlea II is retracted.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 of sites b, f, and j; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites i and f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b; Siltstone Facies of Package 3of site b.

Branta bernicla Linnaeus, 1758

Plate 8 C-E

Referred Specimens:

Coracoid: SDSM 74915

Furcula: SDSM 30128

Tibiotarsus: SDSM 31320; SDSM 31205

Tarsometatarsus: SDSM 30180

Description: The coracoid has a large, flattened facet for articulation with the humerus. The furcula is very robust and rounded. The tibiotarsus has splayed condyles and angled medially. The area between the condyles is flattened. Trochlea II of the tarsometatarsus is retracted toward the shaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b and h.

Branta canadensis Linnaeus, 1758

Plate 9 A-C

Referred Specimens:

Coracoid: SDSM 30860; SDSM 31187; SDSM 32966; SDSM 75657b; SDSM 75826; SDSM 74808

Scapula: SDSM 33044; SDSM 75510; SDSM 31436; SDSM 29134; SDSM 74806

Furcula: SDSM 29117; SDSM 33042; SDSM 75196

Ulna: SDSM 75834

Radius: SDSM 75156

Carpometacarpus: SDSM 75660

Description: The sternal facet of the coracoid is more robust on the edges and thinner in the center. The scapula has a pneumatic foramen, a projected acromion, and a flat glenoid facet. The furcula is very robust and V-shaped. The ulna has rounded condyles with the dorsal condyle extending up the shaft. The radius has a hollow ulnar facet. The carpometacarpus has a robust, rounded extensor process. The pisiform process is sharp and points forward.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites f and g; Mudstone Facies of Package 2 of sites b and h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b, f, and h; Siltstone Facies of Package 3 of site b.

Chen rossi (Cassin, 1861)

Plate 10 A-D

Referred Specimens:

<u>Sternum</u>: SDSM 28259

<u>Coracoid</u>: SDSM 31287; SDSM 74925

<u>Scapula</u>: SDSM 31181; SDSM 29132

<u>Humerus</u>: SDSM 28659; SDSM 29137; SDSM 30136

<u>Tibiotarsus</u>: SDSM 74972; SDSM 74973

Description: The sternum has a tapered coracoidal groove and projecting external spine. The coracoid has a large facet for articlaution with the humerus and a pneumatic fossa. The scapula has a pneumatic foramen, a projected acromion, and a flat glenoid facet. The humerus has a deep capital groove, and a curved bicipital crest. The distal articulation of the tibiotarsus is splayed and the medial condyle angles out.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, g, and h; Mudstone Facies of Package 2 of site f; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b and l.

Clangula hyemalis (Linnaeus, 1758)

Plate 10 E

Referred Specimens:

Furcula: SDSM 30557

Description: The furcula is rounded and flattened medially, with a bends and thins distally. The furcula is robust and U-shaped.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site b.

Mergus serrator Linnaeus, 1758

Plate 11 A

Referred Specimen:

Tibiotarsus: SDSM 74965

Description: The tibiotarsus has a thin fibular crest.

Occurrence: Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f.

Cygnus olor (Gmelin, 1789)

Plate 11 B

Referred Specimens:

Tarsometatarsus: SDSM 31212; SDSM 74822

Description: This specimen is only the central trochlea of the tarsometatarsus. The dorsal side is rounded with a well developed groove. The plantar view also has a well developed groove, and is pointed.

Occurrence: Mudstone Facies of Package 2 of site j; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Order GAVIIFORMES Wetmore and Miller, 1926

Family GAVIIDAE Allen, 1897

Ecology: Loons are migratory water birds that are specialized for diving for fish. Nests are built along shorelines (Sibley et al., 2001).

Referred Specimen:

Tibiotarsus: SDSM 28943

Description: The tibiotarsus has a thin cnemial crest with a sharp projection at the top.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site g.

Order PODICIPEDIFORMES Fürbringer, 1888

Family PODICIPEDIDAE Bonaparte, 1831

Ecology: Grebes require aquatic habitat, which can vary from freshwater to marine. They prefer temperate zones and are migratory. Grebes have nests on floating vegetation. These birds are well adapted to diving to feed and to escape predators. They are therefore rarely found on land (Sibley et al., 2001).

Aechmophorus occidentalis (Lawrence, 1858)

Plate 12 A-E; Plate 13 A-B

Referred Specimens:

Frontoparietals: SDSM 75632; SDSM 75633

Coracoid: SDSM 30307; SDSM 31286; SDSM 75147; SDSM 75148a; SDSM 75148b; SDSM 75148c; SDSM 75151a; SDSM 75151b; SDSM 75126; SDSM 75128; SDSM 31185; SDSM 31186; SDSM 31191b; SDSM 74916; SDSM 74922b; SDSM 32967; SDSM 30118

Scapula: SDSM 33047; SDSM 75653

Furcula: SDSM 30129

Humerus: SDSM 30870; SDSM 75152; SDSM 75153; SDSM 75155; SDSM 74932; SDSM 32968; SDSM 30134; SDSM 75197; SDSM 75127

Radius: SDSM 31192

Carpometacarpus: SDSM 33057

Synsacrum: SDSM 75161; SDSM 31202; SDSM 28422

Femur: SDSM 33066a; SDSM 33066b; SDSM 30879; SDSM 75163; SDSM 31204; SDSM 75507; SDSM 31425; SDSM 28601; SDSM 74964; SDSM 29176; SDSM 29177; SDSM 28398; SDSM 75669; SDSM 75569; SDSM 75570

Tibiotarsus: SDSM 75165; SDSM 75168a; SDSM 75168b; SDSM 74974; SDSM 75169

Tarsometatarsus: SDSM 75521a; SDSM 75521b; SDSM 74986a; SDSM 74986b; SDSM

74990a; SDSM 74990b; SDSM 32972; SDSM 3121; SDSM 29192; SDSM 31207; SDSM 33014; SDSM 28291; SDSM 30178

Description: The frontoparietals are hour-glass-shaped. The coracoid has a rounded, flattened facet for articulation with the humerus. The scapular cotyla and procoracoid are not well developed, and there is a small groove below the humeral facet. The scapula has a square-shaped glenoid facer and a pointed acromion. The furcula is thin and wide with a notch in the center. The proximal humerus has deep ligamental and bicipital furrows, and a well developed deltoid crest. The distal humerus has a curved external condyle, an oval depression for the brachialis muscle, and a flattened attachment for the pronator brevis. The radius has a projection on the distal end. The carpometacarpus has a groove on the distal end of the minor metacarpal and is slightly curved. The synsacrum has a very concave facet on the vertebral body. The antitrochanter is rounded. The femur has a bowed shaft. The trochleae are splayed with a wide fibular groove.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b, f, g, and h; Mudstone Facies of Package 2 of sites b, f, g, j, and l; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b, f, and i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of sites b, f, h, i, and l; Siltstone Facies of Package 3 of site b.

Podiceps auritus Linnaeus, 1758

Referred Specimen:

Coracoid: SDSM 31191a

Description: The coracoid has a well developed sternal facet and is smaller than *Aechmophorus occidentalis*.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Podiceps nigricollis Brehm, 1831

Plate 13 C-D

Referred Specimens:

Coracoid: SDSM 74803

Humerus: SDSM 31290; SDSM 74804

Tarsometatarsus: SDSM 31209; SDSM 33015; SDSM 74982

Description: The coracoid has large facets for articulation with the humerus and scapula. The humerus has a well developed depression for the brachialis muscle. The tarsometatarsus has a thin, rectangular shaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site b; Mudstone Facies of Package 2 of site h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Podilymbus podiceps (Linnaeus, 1758)

Plate 13 E

Referred Specimens:

Coracoid: SDSM 74918

Humerus: SDSM 75154

Description: The coracoid has a wide, oval articular surface, and the acrocoracoid process is curved. The condyles of the humerus are rounded and even. The depression for attachment of the brachialis muscle is well developed.

Occurrence: Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Order PELECANIFORMES Sharpe, 1891

Family PHALACROCORACIDAE Bonaparte, 1854

Ecology: Cormorants are medium- to large-sized water birds with long bodies and necks, and strong, hooked beaks. They are found worldwide, with greatest diversity in tropical and temperate zones (del Hoya et al., 1992). Cormorants are well adapted to aquatic environments and prefer stretches of open water, either freshwater or marine (Sibley et al., 2001). Their skeletons are not as pneumatized as other birds, allowing for easier diving (del Hoya et al., 1992).

Phalacrocorax auritus (Lesson, 1831)

Plate 14 A-B

Referred Specimens:

Scapula: SDSM 33046

Radius: SDSM 30143

Synsacrum: ?SDSM 75162

Tarsometatarsus: SDSM 74821

Description: The scapula has a triangular glenoid facet and the furcular facet is curved. The radius is robust. The head overhangs the shaft. The synsacrum is narrow with a pointed vertebral body. The trochleae of the tarsometatarsus are square and evenly spaced.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of h; Mudstone Facies of Package 2 of sites i and j; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site i; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Family ANHINGIDAE Ridgway, 1887

Ecology: Anhingas are water birds that inhabit open, shallow freshwater wetlands. They nest near water and primarily eat fish (Sibley et al., 2001).

Anhinga anhinga (Linnaeus, 1766)

Plate 14 C

Referred Specimens:

Ulna: SDSM 30149; SDSM 31954

Tibiotarsus: SDSM 30875

Description: The ulna as a rounded distal condyle and the ventral condyle is sharp. The ulna has a pointed distal articulation. The tibiotarsus has a thin cnemial crest.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 of sites b and f.

Order CICONIIFORMES Garrod, 1874

Family THRESKIORNITHIDAE Richmond, 1917

Ecology: Ibises are large wading birds that inhabit a variety of wetlands and freshwater marshes, where they feed on aquatic prey (Sibley et al., 2001).

Eudocimus ruber (Linnaeus, 1758)

Plate 14 D

Referred Specimen:

Humerus: SDSM 30133

Description: The humerus has a horizontal bicipital crest and a small pneumatic fossa.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of h.

Order ARDEIFORMES Wagler, 1831

Family ARDEIDAE Vigors, 1825

Ecology: Herons are wading birds that live in coastal environments to interior wetlands, and largely feed on fish (Sibley et al., 2001).

Ardea herodias Linnaeus, 1758

Plate 15 A-D

Referred Specimens:

Sternum: SDSM 74907

Ulna: SDSM 75158

Carpometacarpus: ?SDSM 31200

Digit 2, phalanx 1?: SDSM 32970

Tarsometatarsus: SDSM 74988

Description: The coracoidal groove of the sternum overlaps and has an external spine. The condyles of the ulna are rounded with a process on the ventral condyle. The carpometacarpus has a long extensor process. The pisiform process is broken. The digit 2, phalanx 1 is thin and has double depressions. The trochlea of the tarsometatarsus are distally level, and are splayed.

Occurrence: Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Order GRUIFORMES Bonaparte, 1854

Family GRUIDAE Vigors, 1825

Ecology: Cranes inhabit open habitats of freshwater wetlands to uplands. They are migratory and are opportunistic feeders (Sibley et al., 2001).

Grus ?*canadensis* (Linnaeus, 1758)

Referred Specimen:

Humerus: SDSM 30868

Description: The humerus has a rounded condyle that ends sharply, and there is a small depression on the side of the dorsal condyle.

Occurrence: Mudstone Facies of Package 2 of site b.

Order RALLIFORMES Reichenbach, 1854

Family RALLIDAE Reichenbach, 1854

Ecology: Coots live mostly in marshlands, with some species preferring more terrestrial environments, although most nest near water. They are opportunistic feeders and migratory (Sibley et al., 2001).

Fulica sp. Linnaeus, 1758

Plate 16 A

Referred Specimen:

<u>Ulna</u>: SDSM 31193

Description: The ulna has a well developed projection on the ventral cotyle and a slightly bowed shaft.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Fulica americana Gmelin, 1789

Plate 16 B-E

Referred Specimens:

<u>Coracoid</u>: SDSM 30270; SDSM 30271; SDSM 74920; SDSM 74922a

<u>Scapula</u>: SDSM 30864

<u>Humerus</u>: SDSM 30873; SDSM 30871

<u>Tarsometatarsus</u>: SDSM 31208

Description: The coracoid has a shallow scapular cotyla, an oval facet for articulation with the humerus, and a sharp procoracoid process. The scapula has a small groove on the glenoid facet and a square acromion. The distal humerus is very splayed and the condyles are rounded. The tarsometatarsus has a rounded and concave medial cotyle, and a small tendinal bridge.

Occurrence: Mudstone Facies of Package 2 of site b; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f; Conglomeratic Sandstone/Siltstone Facies of Package 3 of site h.

Order CHARADRIIFORMES Fürbringer, 1888

Family SCOLOPACIDAE Vigors, 1825

Ecology: Sandpipers live in coastal and inland wetlands, but others inhabit open steppe, grassland, or marsh environments (del Hoya et al., 1996). Most members of this family breed near water, often in taiga or tundra habitats (Sibley et al., 2001).

?*Tringa* sp. Linnaeus, 1758

Plate 17 A-B

Referred Specimens:

<u>Scapula</u>: SDSM 30865

<u>Tibiotarsus</u>: SDSM 30171

Description: The scapula has a rounded glenoid facet and a pointed acromion. The proximal tibiotarsus has a lateral cnemial crest.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 of site b.

Tringa melanoleuca Gmelin, 1789

Plate 17 C

Referred Specimens:

Carpometacarpus: SDSM 74772; SDSM 74805

Tarsometatarsus: SDSM 30182

Description: The carpometacarpus has a spiky, forward facing pisiform process. The extensor process points up.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 of site h.

Family CHARADRIIDAE (Fürbringer, 1888)

Ecology: Plovers are medium-sized birds with short, pointed bills. Their present distribution includes all regions except Antarctica, and they utilize a variety of habitats, including wet and dry open habitats, a variety of wetlands, coastal shorelines, grasslands, and tundra (del Hoya et al., 1996). Plovers are migratory and feed mostly on invertebrates (Sibley et al., 2001).

Charadrius alexandrius Linnaeus, 1758

Plate 17 D

Referred Specimen:

Humerus: SDSM 30558; SDSM 30559; SDSM 30927; SDSM 29955

Description: The humerus has two pneumotricipital fossa, a triangular deltoid crest, and a projecting supracondylar process.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site; Mudstone Facies of Package 2 of sites b and h.

Family LARIDAE Bonaparte, 1831

Ecology: Gulls typically live in coastal environments, but also in a variety of inland freshwater habitats feeding on fish (del Hoya et al., 1996). Many species are migratory (Sibley et al., 2001).

Larus californicus Lawrence, 1854

Referred Specimen:

Coracoid: SDSM 75511

Description: The coracoid has a penetrating foramen, with a concave sternal facet.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 3 of site b.

Larus occidentalis Audubon, 1839

Plate 18 A

Referred Specimen:

Humerus: SDSM 69628

Description: The humerus is large with double pneimotricipital fossa. The distal end has a deep depression for the brachialis muscle and a projecting supracondylar process.

Occurrence: No locality data.

Sterna forsteri Richardson, 1832

Plate 18 B

Referred Specimen:

Radius: SDSM 30146

Description: The proximal radius is small. The neck thins, then flares and twists distally.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Family ALCIDAE Vigors, 1825

?*Uria* sp. Brisson, 1760

Plate 18 C

Ecology: This group of sea-birds feed on fish and invertebrates, but breed on land, usually cliff ledges (Sibley et al., 2001).

Referred Specimen:

Humerus: SDSM 2995

Description: The humerus has two pneumotricipital fossa, a triangular deltoid crest, and a projecting supracondylar process. Designation to this genera is uncertain, but is the closest match.

Occurrence: Mudstone Facies of Package 2 of site h.

Order FALCONIFORMES Seebohm, 1890

Family FALCONIDAE Vigors, 1824

Ecology: Falcons are predators that prefer a variety of open habitats, such as coastal marshes, grasslands, prairie deserts, tidal flats, and Arctic tundra (Sibley et al., 2001).

Falco sp. Linnaeus, 1758

Plate 18 D

Referred Specimen:

Ulna: SDSM 30150

Description: The ulna has a rounded and concave ventral condyle.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Family ACCIPITRIDAE Vieillot, 1816

Plate 19 A-B

Ecology: Hawks, eagles, and kites are migratory predators that typically utilize most terrestrial habitats, feeding on mammals, birds, fish, and reptiles. Moost build their nests in trees (Sibley et al., 2001).

Referred Specimens:

Coracoid: SDSM 74919

Ungual: SDSM 30084

Description: The coracoid has a penetrating foramen, with a concave sternal facet. The ungual is very curved and has a sharp end.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f.

Aquila chrysaetos (Linnaeus, 1758)

Plate 19 C

Referred Specimen:

Radius: SDSM 30142

Ungual: SDSM 75002

Description: The radius has two articulations below the head. The articulation of the ungual has a notch in the center. The ungual is very curved and thin.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h; Mudstone Facies of Package 2 and Conglomeratic Sandstone/Siltstone Facies of Package 3 of site f.

Circus cyaneus (Linnaeus, 1766)

Plate 19 D

Referred Specimen:

Carpometacarpus: SDSM 31956

Description: The minor metacarpal of the carpometacarpus attachment is v-shaped, and has a well developed tendon groove.

Occurrence: Mudstone Facies of Package 2 of site f.

Order STRIGIFORMES (Wagler, 1830)

Ecology: Owls are terrestrial and feed on invertebrates and vertebrates. Species are non-migratory to slightly migratory (Sibley et al., 2001).

Family STRIGIDAE Gray, 1840

Otus ?kennicotti (Elliot, 1867)

Plate 20 A

Referred Specimen:

Sternum: SDSM 74799

Description: The sternum has a slight overlap of the coracoidal groove.

Occurrence: Mudstone Facies of Package 2 of site h.

Order PASSERIFORMES Linnaeus, 1758

Family CORVIDAE Vigors, 1825

Ecology: Crows, ravens, and jays are perching birds that utilize most terrestrial habitats. They are omnivorous, nest in trees, and are non-migratory to partially migratory (Sibley et al., 2001).

Cyanocitta cristata (Linnaeus, 1758)

Plate 20 B

Referred Specimen:

Carpometacarpus: SDSM 30166

Description: The minor metacarpal extends past the distal major metacarpal. The pisiform is small.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Family LANIIDAE Linnaeus, 1758

Ecology: This family is comprised of predatory songbirds feeding on insects and small vertebrates, utilizing open habitats ranging from tundra to grasslands. Northern species are migratory (Sibley et al., 2001).

Lanius ludovicianus Linnaeus, 1766

Plate 20 C

Referred Specimen:

Ulna: SDSM 30154

Description: The ulna has rounded condyles with a projection between the two.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Family BOMBYCILLIDAE Swainson, 1831

Ecology: Waxwings are frugivorous, woodland songbirds that migrate (Sibley et al., 2001).

?*Bombycilla cedorum* Vieillot, 1808

Plate 20 D

Referred Specimens:

Ulna: SDSM 30563

Description: The ulna has a very rounded cotyle with a sharp olecranon.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site b.

Family FRINGILLIDAE Linnaeus, 1758

Plate 20 E

Ecology: Fringillids are migratory, arboreal songbirds that feed on seeds and buds (Sibley et al., 2001).

Referred Specimens:

Coracoid: SDSM 30120

Carpometacarpus: SDSM 30169

Tibiotarsus: SDSM 30565

Description: The coracoid is thin, and the acrocoracoid process is not well developed. The carpometacarpus is very small. The pisiform process, extensor process, and the minor metacarpal are broken. The tibiotarsus is very small and thin. The shaft is bowed and has a thin fibular crest.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of sites b and h.

Family ICTERIDAE Brisson, 1760

Ecology: Blackbirds inhabit open habitats feeding on insects and grains. Northern species are migratory and they nest on the ground, in trees, or on aquatic vegetation (Sibley et al., 2001).

Xanthocephalus xanthocephalus (Bonaparte, 1826)

Plate 21 A

Referred Specimen:

Premaxilla: SDSM 28995

Description: The distal end of the partial premaxilla is pointed. The nasal process of the premaxilla is thin.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site g.

Sturnella neglecta Audubon, 1844

Plate 21 B

Referred Specimens:

Ulna: SDSM 30152; SDSM 30153

Description: The ulna has rounded condyles with a projection between the two. The ulna has a prominent olecranon, and the cotyles are not well developed.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

?*Euphagus* ?*cyanocephalus* (Wagler, 1829)

Plate 21 C

Referred Specimen:

Tibiotarsus: SDSM 30174

Description: The condyles of the tibiotarsus are rounded. The area above the supratendinal bridge is flattened and for muscle attachment.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Family ?VIREONIDAE Swainson, 1837

Plate 21 D

Ecology: Vireos are foliage-gleaning songbirds that exploit thicket and forest habitats, feeding on insects and fruits (Sibley et al., 2001).

?*Vireo* Viellot, 1808

Referred Specimen:

Humerus: SDSM 30132

Description: The humerus has a robust head. The distal condyles are broken.

Occurrence: Conglomeratic Sandstone/Siltstone Facies of Package 2 of site h.

Habitat Divisions

The fossil bird families from the Fossil Lake Formation that are described above are divided here into three groupings based on their habitat preferences: diving birds, shallow-water birds, and terrestrial birds. These groupings allow for comparisons of fossil avian diversity through the Fossil Lake Formation.

The first category includes the Gaviidae, Podicipedidae, Phalacrocoracidae, and Anhingidae, which are classified as diving birds. These families are highly specialized for underwater feeding by diving (Sibley et al., 2001). Therefore, for strata containing these fossils, water depth is inferred to be moderate to deep.

Shallow-water birds are the second category and includes the families Anatidae, Threskiornithidae, Ardeidae, Gruidae, Rallidae, Scolopacidae, Charadriidae, Laridae, and Alicdae. Although ducks and geese are water birds, the required depth is shallower than the families in the previous group. Two genera of ducks identified in this study, *Aythya* and *Mergus*, are diving ducks. A total of three specimens of these genera have been found, and therefore, will be included in this category. The families of the shallow-water birds group are found near water, where they feed by wading. Most of this group nest near water and are migratory (Sibley et al., 2001). The presence of at least shallow water is inferred from the presence of birds of this group.

The final category is the terrestrial birds, including Phasianidae, Falconidae, Accipitridae, Strigidae, Corvidae, Laniidae, Bombycillidae, Fringillidae, Icteridae, and ?Vireonidae. The grouse (Phasianidae) is adapted for walking in terrestrial habitats and today inhabits arid environments (Sibley et al., 2001). The rest of this group exploits a variety of habitats, not closely linked with water, and generally associated with wooded areas (Sibley et al., 2001). Terrestrial birds represent the outer fringe of the lake system.

2.7: DISCUSSION

Fossil Avifauna

Although bird fossils have been found in the younger facies of the Fossil Lake Formation, the older facies are more fossiliferous and are the focus of this discussion. Fossils collected during 2006 and 2008 field seasons were used in this study. Fossils were recovered from the Conglomeratic Sandstone/Siltstone Facies (CSF) and the Mudstone Facies (MF) of Package 2, the CSF and the Siltstone Facies (SF) of Package 3, and the CSF of Package 4.

Figure 2.13 details the occurrences of each genus throughout each facies of Packages 2-4. Overall, diversity decreases up-section, from 23 genera in the CSF of

Package 2 to a single genus from the CSF of Package 4. The CSF of Package 2 has 23 genera, the MF of Package 2 has 15 genera, the CSF of Package 3 has 10 genera, the SF of Package 3 has 4 genera, and the CSF of Package 4 has only 1 genus. *Anas* is the only genus that has been recovered from each of these facies. *Aechmophorus* is found in all of the facies of Packages 2 and 3. Most of the terrestrial bird genera were found in the CSF of Package 2, and only three genera were found in the MF of Package 2. No terrestrial birds have been recovered from Packages 3 or 4.

Most fossils from the Fossil Lake Formation have excellent preservation. Although few skeletons are found, many of the bones are complete and numerous fossil eggshells have been recovered (Figure 2.14). It is inferred from the preservation that taphonomic overprinting was low. Disarticulation probably resulted from scavenging. The bones were either buried near the shoreline or carried out to deeper water. The abundance of shallow-water birds and scarcity of terrestrial birds is likely an artifact of the lack of true terrestrial deposits.

Fossils included here were recovered from 10 localities within the eastern part of Fort Rock Basin, spanning approximately 5 km^2. The spatial relationship between these localities is demonstrated in Figure 2.15. Facies data and the corresponding abundances of the bird eco-groups are also included in this figure. These fossil localities are in close proximity and represent a small part of the much larger Fort Rock Basin. As a result, no pattern between the geographic location of each site and the bird fauna is recognized.

The fossil data in stratigraphic context are summarized in Figure 2.16. The CSF of Packages 2 and 3 are the most fossiliferous. Shallow-water birds are the most abundant eco-group of each facies. Diversity decreases from Package 1 through Package

4. Although most of the fossil birds from the Fossil Lake Formation are migratory, it is unlikely that the collections from individual facies represent migration events. Instead, each facies represents deposition during several thousand years, and consequently the collections are time-averaged.

Paleoclimate Discussion

Although the paleoclimate of Fossil Lake has not been rigorously studied, surrounding areas have been. Summer Lake, Oregon, located 80 km southwest of Fossil Lake, is one such example (Cohen et al., 2000; Negrini et al., 2000). Correlation between lakes is possible because of the presence of the diagnostic tephra beds. The 23.2-ka Trego Hot Springs (Rieck et al., 1992) and the 47-ka Marble Bluff Mount St. Helens tephra (Davis, 1985) are found at both localities. The Fossil Lake Formation lacks other tephras found at Summer Lake because of numerous unconformities within the section (Martin et al., 2005). The proximity of the two localities and the temporal constraints allow for inferences to be made about the climate of Fossil Lake based, in part, on correlation to Summer Lake.

A paleoclimate study of Summer Lake was completed through the use of sedimentology, paleontology, and geochemistry (Cohen et al., 2000; Negrini et al., 2000). Summer Lake is located in the basin of pluvial Lake Chewaucan (Negrini et al., 2000), and the sediments were obtained by cores that span 250,000-5,000 years ago (Benson et al., 1997; Cohen et al., 2000). The stratigraphy is dominated by silts containing ostracodes and 11 basaltic tephras (Cohen et al., 2000; Negrini et al., 2000). Similar to Fort Rock Lake, the water level of Lake Chewaucan waxed and waned several times.

During the driest intervals, the lake sediments were subaerially exposed, as evidenced by paleosols (Cohen et al., 2000).

Ostracodes are common in the Summer Lake sediments, and the identification of individual species is useful in reconstructing past environmental conditions, such as salinity, temperature, and chemical composition of freshwater environments (Holmes, 2001). Prior to 200 ka, Summer Lake was saline. This interval was followed by an abrupt change to fresher water until 165 ka when salinity increased again (Cohen et al., 2000).

The data collected from the Summer Lake cores are illustrated in Figure 2.17 and suggest that the climate was generally becoming wetter and cooler from 236-165 ka. From 165-158 ka, the climate was drier and warmer. There is an unconformity until 118 ka, when deposition began again. Therefore, the duration of the drier and warmer period is unknown. The climate became drier from 118-90 ka, followed by a wetter climate from 89-50 ka. The temperature was generally cold from the interval from 89-17 ka, but had a brief warm interval from 27-23 ka. Finally, the climate became drier from 40-32 ka (Cohen et al., 2000). The fluctuations in temperature and precipitation at Summer Lake result from climate dynamics associated with glacial and interglacial periods, as the changes are similar to the global ice volume record from marine oxygen isotopes (Cohen et al., 2000; Negrini et al., 2000). Precipitation data are not known for the interval beginning 50 ka, but the Summer Lake data indicate a cold interval with a short warm period from 27-23 ka (Cohen et al., 2000).

The rare earth element geochemistry (REE) of stratigraphically collected fossils from the Fossil Lake Formation indicates low salinity conditions during lacustrine deposition of Packages 1-4 but increased salinity during deposition of Packages 5-7 (Martin et al., 2005). From my facies analysis, Packages 1-3 represent repeated changes in water levels from shoreline to deeper-water (offshore) environments. Although lake levels were fluctuating during this time, salinity levels appear to have remained low. Packages 4-7 consist of repeated alternations of the CSF and SF, and lacking the deeper water deposition represented by MF, which is consistent with higher salinity values determined by REE geochemistry (Martin et al., 2005). The topmost package of the Fossil Lake Formation contains the XSF and MF. The XSF suggests a dry interval, based on the presence of root traces and eolian cross-beds. The MF of Package 8 contains associated salmonid fish skeletons, representing offshore deposition approximately 10 ka at the beginning of the last interglacial stage. Overall, Packages 1-4 indicate a wet and likely cold interval and Packages 5-7 represent a transitional interval from wet to dry. Package 8 represents a dry and cold interval followed by a wet and warm interval. Compilation of the temperature and precipitation data for Summer Lake (Cohen et al., 2000), and salinity levels from Fossil Lake (Martin et al., 2005) for all of these packages are summarized in Figure 2.17.

The temporal constraints of the tephra of the Fossil Lake Formation allows for correlation with the Marine Isotope Stages (Figure 2.7) as summarized in Gibbard et al. (2007). Correlation can only be made at tephra layers and, therefore, correlation of stage boundaries to the Fossil Lake strata is uncertain. In addition, discontinuous deposition suggests that not all stages are represented. The MF of Package 1 was deposited during glacial stage 16, the CSF of Package 2 was deposited during the interglacial stage 15, the CSF of Package 3 was deposited during stage 5a, the SF of Package 4 was deposited during stage 3, and the SF of Package 7 was deposited during stage 2. Fossil salmonid from the MF of Package 8 yield an age of 10 ka (Martin, 2006), which signifies deposition during the present interglacial stage.

Glacial maxima are recorded twice within the Fossil Lake Formation, the first in the MF of Package 1, and the second in the SF of Package 7. Both facies are interpreted as offshore lacustrine environments. The warmest intervals, based on marine isotope stages, occur within the CSF of Packages 2 and 3, which are interpreted as shoreline environments based on facies analysis. Bird fossils are the most abundant in these intervals, with shorebird abundance of 66% and 58%, respectively. Packages 4-7 were deposited during small-scale fluctuations between the end of interglacial stage 5a and the glacial stage 2. This is reflected in the Fossil Lake stratigraphy as four packages of CSF-SF, where water level fluctuations are not as pronounced as in the lower packages.

2.8: CONCLUSIONS

The units of the Pleistocene Fossil Lake Formation are divided into four facies that are interpreted as representing offshore, shoreline, and paludal lacustrine environments. These facies form eight, upwardly fining packages that record repeated episodes of lake deepening. Changes in water depth are abrupt, as seen in the juxtaposition of facies and root traces locally present in the top of the Mudstone Facies with fossil fish. Deposition of the formation is temporally constrained by the tephras within the section. The tephras allow for correlation with previous climate studies of Summer Lake, Oregon, and with the marine isotope stages. The finest-grained facies, and the inferred deepest lake conditions occurred during glacial maxima.

The fossil bird specimens described herein increase the known bird diversity by three families, eight genera, and one species. The inclusion of stratigraphic data with the fossil avifauna can be used to corroborate broad depositional environments. The stratigraphic control also allows for determination of diversity and abundance trends through time. Most bird fossils were found within the CSF of Packages 2 and 3, and diversity of genera decreases up-section from Packages 2-4. A significant unconformity occurred between Packages 2 and 3, representing a jump from Marine Isotope Stage 15 to 5a. Inferred temperature, water depth, and sample size are similar for the CSF of these two packages, but the diversity of bird genera decreases from 23 to 9 from Package 2 to 3. Therefore, variables besides temperature and water depth also play a role in controlling avian diversity. Packages 3-4 were deposited as the climate cools toward the Last Glacial Maximum.

Table 2.1: Fossil Lake Formation facies table.

Table 2.1: Descriptions of Fossil Lake Formation Facies

Facies	Average Thickness	Average Grain Size	Structures	Color	Bedding	Depositional Environment
Conglomeratic Sandstone and Siltstone Facies (CSF)	0.40 m	68.1 μm (matrix); 1-5 cm (gravel)	None	Moderate yellow brown (10YR 5/4) to light olive gray (5Y 5/2)	Graded	Marginal lacustrine
Cross-bedded Siltstone Facies (XSF)	0.65 m	37.6 μm	Root traces; cross-beds	Dark yellowish brown (10YR 5/2)	Cross-bedded	Marginal lacustrine to on-shore
Siltstone Facies (SF)	0.40 m	10.8 μm	None	Moderate yellow brown (10YR 5/4) to light olive gray (5Y 5/2)	Massive	Marginal to offshore lacustrine
Mudstone Facies (MF)	0.45 m	6.7 μm	Root traces	Pale greenish yellow (10Y 8/2) to yellowish gray (5Y 7/2)	Massive	Offshore lacustrine to paludal

Table 2.2: Stratigraphic position, correlated tephras, and ages of the Fossil Lake Formation tephras.

Table 2.2: Stratigraphic position, correlated tephras, and ages of the five Fossil Lake Formation tephras, from Martin et al., 2005.

Fossil Lake Tephra	Unit	Correlated Tephra	Age in ka
E	13	Trego Hot Springs	23.2
D	7	Marble Bluff Mount St. Helens	47
C	4	Tulelake T64	95
B	2	Dibekulewe	610
A	1	Rye Patch Dam	646

Table 2.3: Comparison of bird taxa from Howard (1946) and this study. An asterisk (*) indicates an extinct species.

Order/Family	Species	Howard (1946)	This study
Galliformes			
	*Dendragapus lucasi**	X	
	*Dendragapus nanus**	X	
	Tympanachus phasianellus	X	
	Centrocercus urophasianus	X	X
	*Paleotetrix gilli**	X	
Anseriformes			
	Cygnus buccinator	X	
	*Sthenelides paloregonus**	X	
	Branta canadensis	X	X
	Branta bernicla	X	X
	Anser albifrons	X	
	Chen caerulescens	X	
	Chen rossii	X	X
	Branta sp.	X	X
	*Branta propinqua**	X	
	Anabernicula sp.*	X	
	Anas platyrhynchos	X	X
	Anas acuta	X	X
	Anas crecca	X	X
	Anas cyanoptera	X	
	Anas americana	X	X
	Anas clypeata	X	X
	Aythya americana	X	X
	?*Aythya collaris*	X	
	Aythya affins	X	X
	Bucephala albeola	X	
	Clangula hyemalis	X	X
	Melanitta perspicillata	X	
	Oxyura jamaicensis	X	
	Mergus merganser	X	
	Mergus serrator	X	X
Gaviiformes			
Gaviidae			X

Order/Family	Species	Howard (1946)	This study
Podicipediformes			
	Aechmophorus occidentalis	X	X
	Podiceps nigricollis	X	X
	*Podiceps parvus**	X	
	Podilymbus podiceps	X	X
Pelecaniformes			
	Pelecanus erythrorhynchos	X	
	*Phalacrocorax macropus**	X	X
	Phalacrocorax auritus?	X	X
	Anhinga anhinga		
Ciconiiformes			
	Botaurus lentiginosus	X	
	Ciconia sp	X	
	*Phoenicopterus copei**	X	
	Eudocimus ruber		X
Ardeiformes			
	Ardea herodias	X	X
Gruiformes			
	Grus ?canadensis		X
Ralliformes			
	Rallus limicola	X	
	Fulica americana	X	X
Charadriiformes			
Scolopacidae	*Tringa melanoleuca*	X	X
Charadriidae	?*Numenius americanus*	X	
	Limnodromus griseus	X	
	Recurvirostra americana	X	
	Himantopus mexicanus	X	
	Phalaropus lobatus	X	
	Charadrius alexandrius		X
Laridae	*Stercorarius shufeldti**	X	
	*Larus robustus**	X	
	*Larus oregonus**	X	
	Larus californicus	X	X

Order/Family	Species	Howard (1946)	This study
	Larus occidentalis		X
	Larus philadelphia	X	
	Sterna forsteri	X	X
	Chlidonias niger	X	
Alcidae	?*Uria*		X
Falconiformes			
	Haliaeetus leucocephalus	X	
	Aquila chrysaetos	X	X
	*Spizaetus pliogryps**	X	
	*Hypomorphnus? sodalis**	X	
	Circus cyaneus	X	X
	*Falco oregonus**	X	
	Falco sp.		X
Strigiformes			
	Bubo virginianus	X	
	Otus ?kennecotti		X
Piciformes			
	Colaptes cafer	X	
Passeriformes			
Corvidae	*Corvus corax*	X	
	Cyanocitta cristata		X
Icteridae	*Euphagus cyanocephalus*	X	
	Xanthocephalus xanthocephalus	X	X
	Sturnella neglecta		X
	?*Molothrus ater*	X	
	?*Agelaius*	X	
Lannidae	*Lanius ludovicianus*		X
Bombycillidae	?*Bombycilla cedorum*		X
Fringillidae			X
Vireonidae	?*Vireo* sp.		X

Figure 2.1: Map of Lake County, Oregon, documenting the location of the Fossil Lake Study Area. The dark line represents the areal extent of Fort Rock Lake.

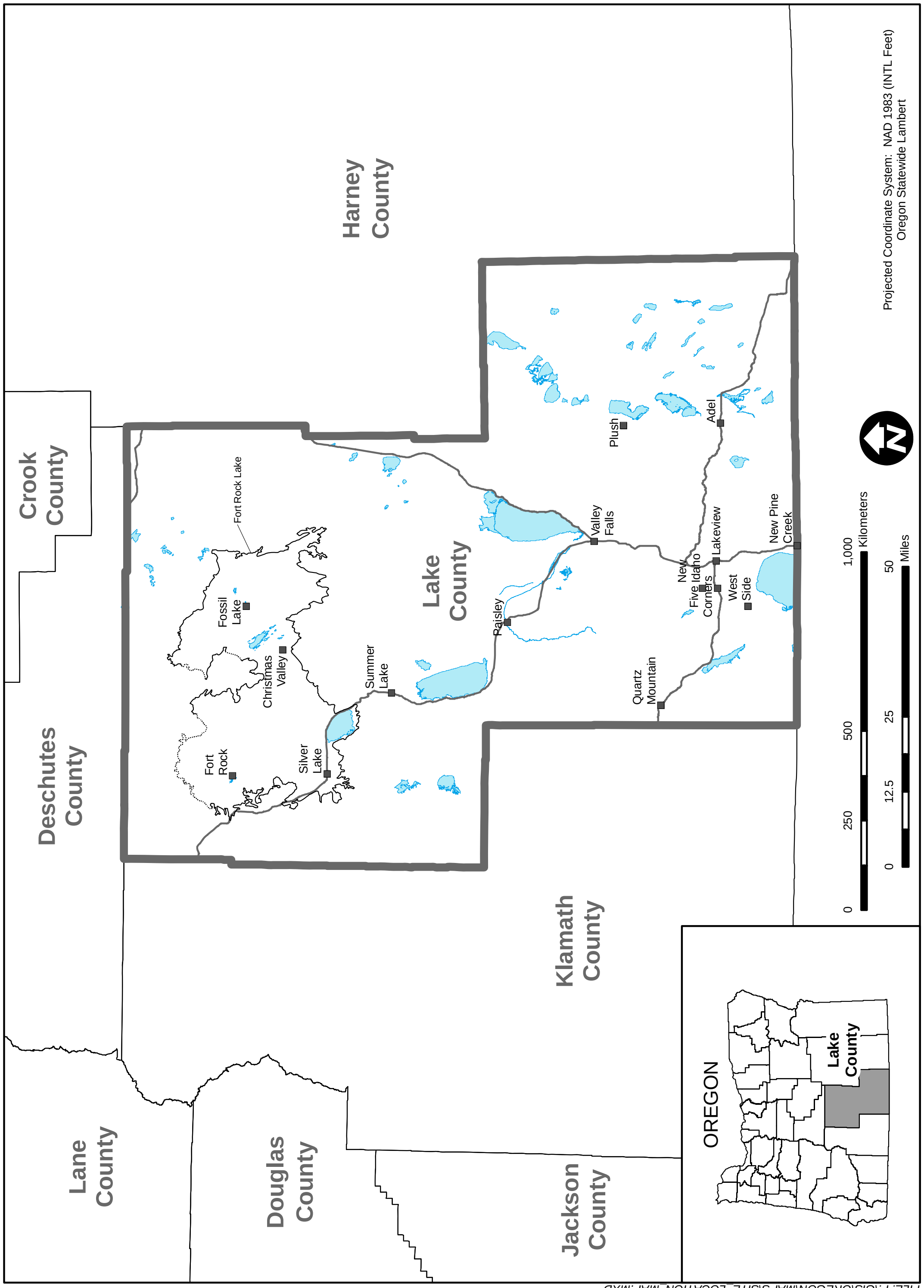
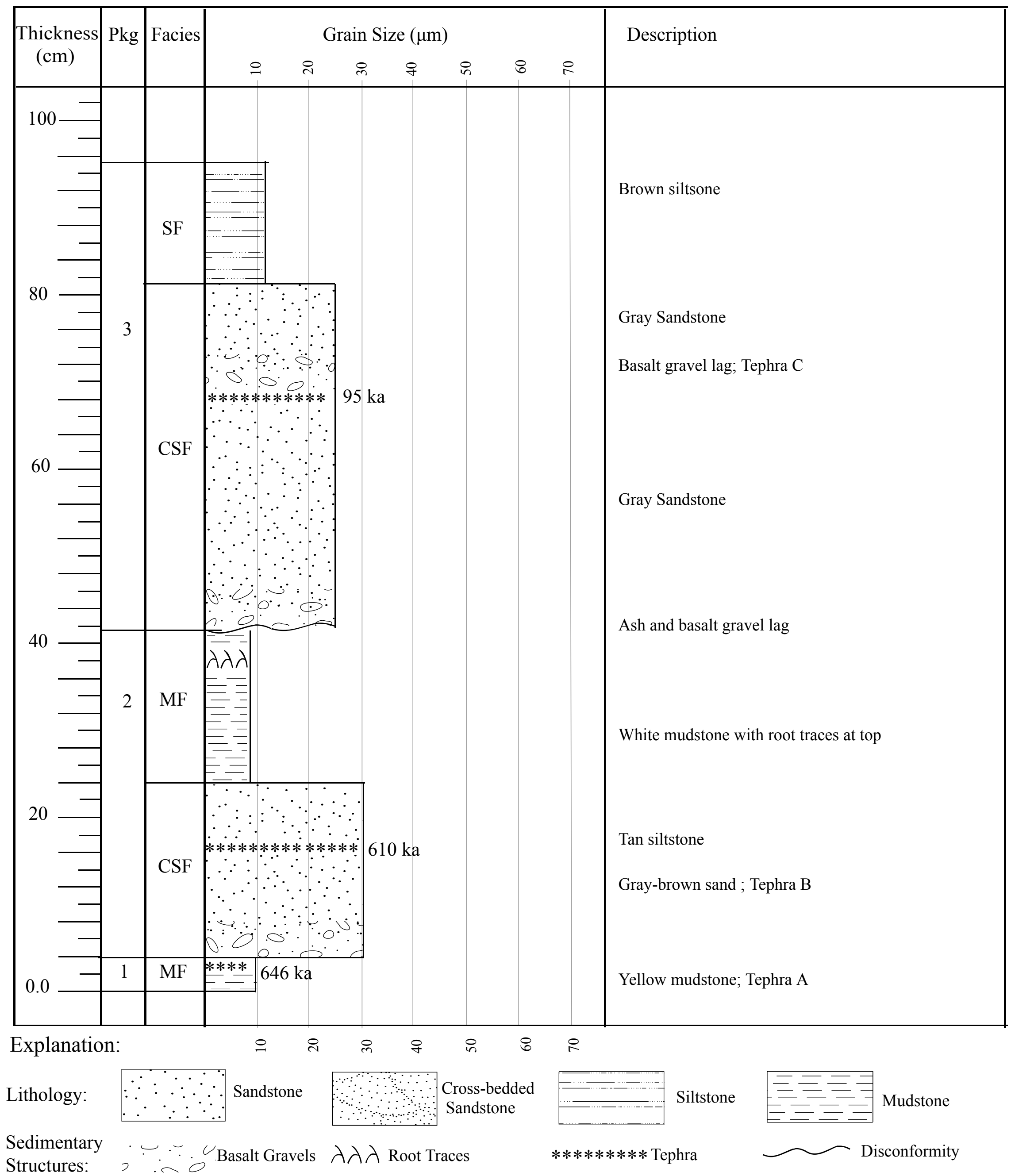

Harney County
Crook County
Deschutes County
Lake County
Lane County
Douglas County
Jackson County
Klamath County
Fort Rock Lake
Fossil Lake
Christmas Valley
Fort Rock
Silver Lake
Summer Lake
Paisley
Valley Falls
Plush
Adel
Lakeview
New Pine Creek
New Idaho
Five Corners
West Side
Quartz Mountain
N
0 250 500 1,000 Kilometers
0 12.5 25 50 Miles
Projected Coordinate System: NAD 1983 (INTL Feet)
Oregon Statewide Lambert
OREGON
Lake County
FILE: F:\GIS\OREGON\MAPS\SITE_LOCATION_MAP.MXD

Figure 2.2: Stratigraphic column from site g of the Fossil Lake Formation.

Site g



Thickness (cm)
Pkg
Facies
Grain Size (µm)
Description
10
20
30
40
50
60
70
100
80
60
40
20
0.0
3
2
1
SF
CSF
MF
CSF
MF
95 ka
610 ka
646 ka
Brown siltstone
Gray Sandstone
Basalt gravel lag; Tephra C
Gray Sandstone
Ash and basalt gravel lag
White mudstone with root traces at top
Tan siltstone
Gray-brown sand ; Tephra B
Yellow mudstone; Tephra A
Explanation:
Lithology:
Sandstone
Cross-bedded Sandstone
Siltstone
Mudstone
Sedimentary Structures:
Basalt Gravels
Root Traces
Tephra
Disconformity

Figure 2.3: Stratigraphic column from site l of the Fossil Lake Formation.

Site l

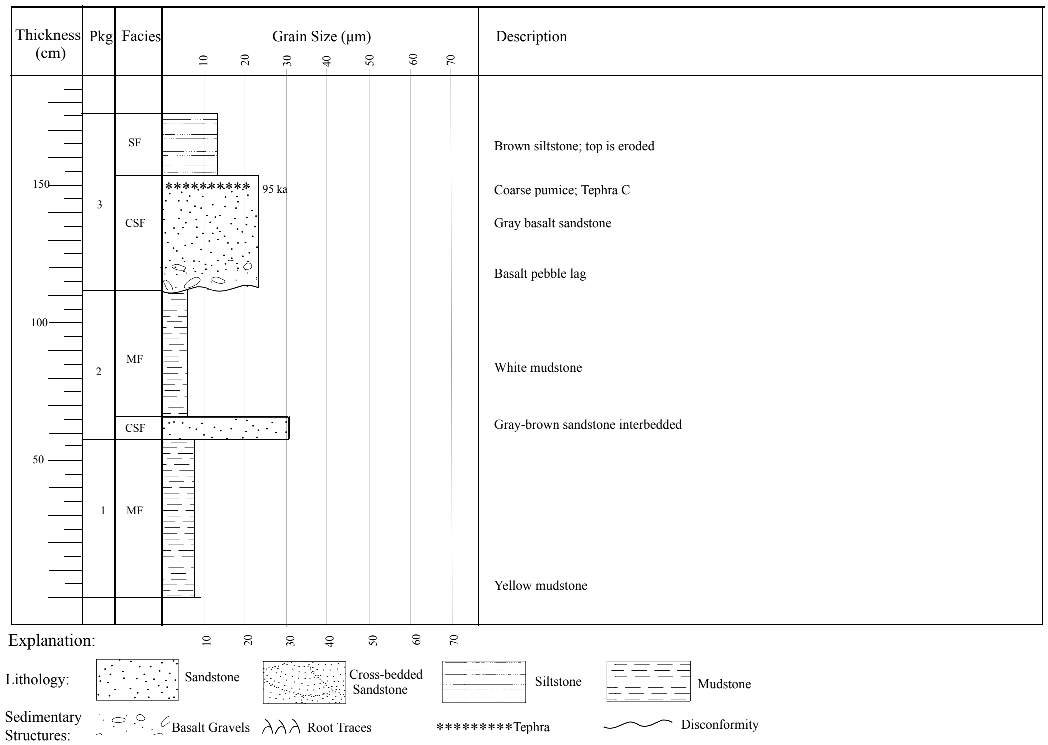
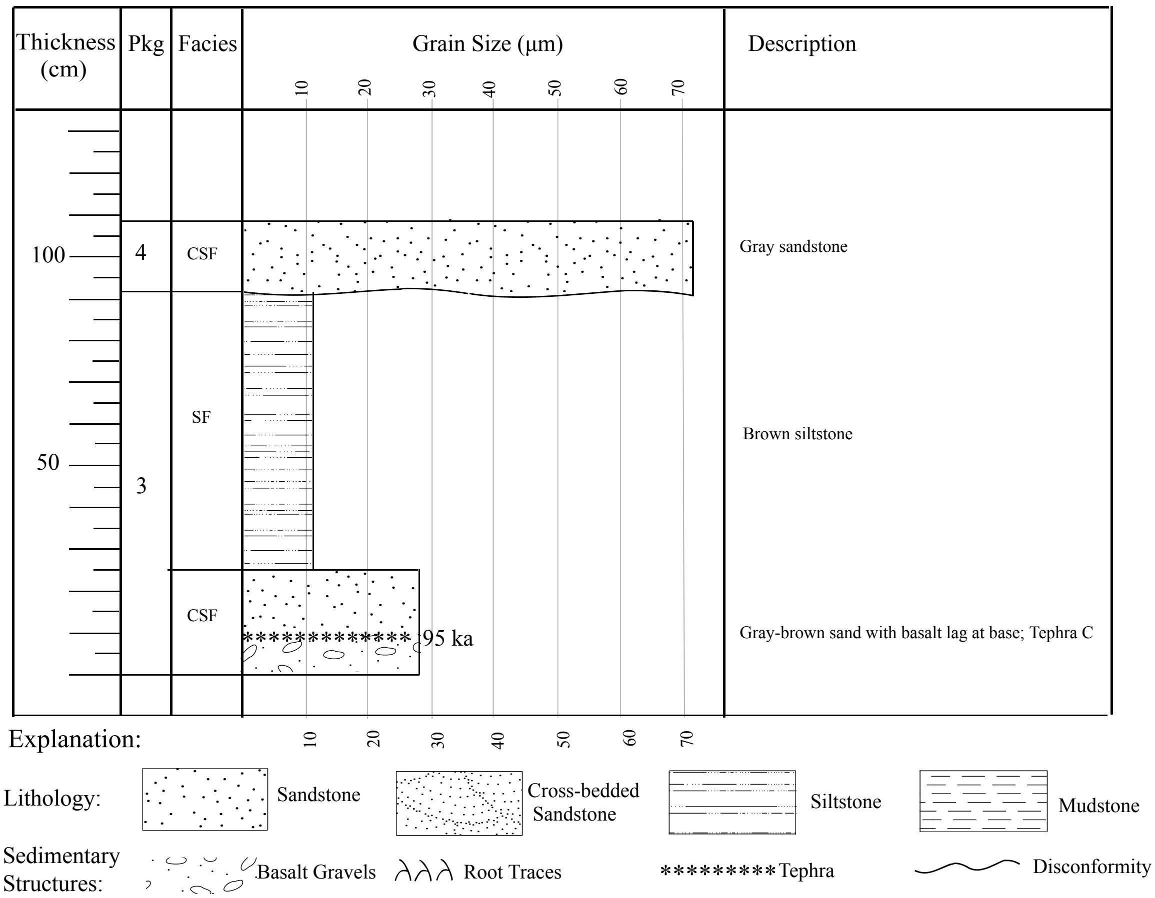

Thickness (cm)
Pkg
Facies
Grain Size (µm)
10 20 30 40 50 60 70
Description
150
100
50
3
2
1
SF
CSF
MF
CSF
MF
95 ka
Brown siltstone; top is eroded
Coarse pumice; Tephra C
Gray basalt sandstone
Basalt pebble lag
White mudstone
Gray-brown sandstone interbedded
Yellow mudstone
Explanation:
Lithology:
Sandstone
Cross-bedded Sandstone
Siltstone
Mudstone
Sedimentary Structures:
Basalt Gravels
Root Traces
*********Tephra
Disconformity

Figure 2.4: Stratigraphic column from site cc of the Fossil Lake Formation.

Site cc



Thickness (cm)
Pkg
Facies
Grain Size (µm)
Description
10
20
30
40
50
60
70
100
50
4
3
CSF
SF
CSF
Gray sandstone
Brown siltstone
Gray-brown sand with basalt lag at base; Tephra C
95 ka
Explanation:
Lithology:
Sandstone
Cross-bedded Sandstone
Siltstone
Mudstone
Sedimentary Structures:
Basalt Gravels
Root Traces
Tephra
Disconformity

Figure 2.5: Stratigraphic column from site a of the Fossil Lake Formation.

Site a

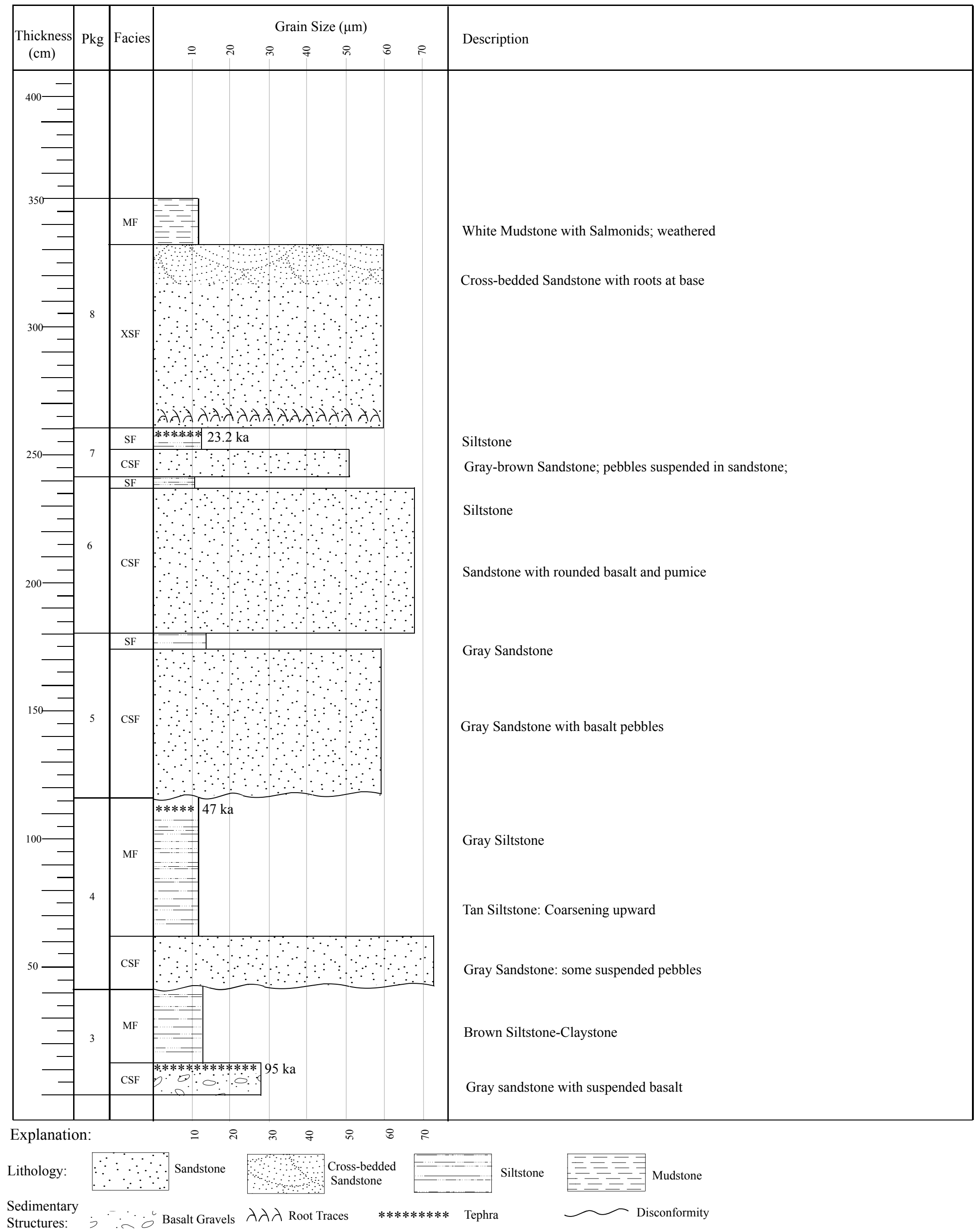

Thickness (cm)
Pkg
Facies
Grain Size (µm)
10
20
30
40
50
60
70
Description
400
350
300
250
200
150
100
50
8
7
6
5
4
3
MF
XSF
SF
CSF
SF
CSF
SF
CSF
MF
CSF
MF
CSF
23.2 ka
47 ka
95 ka
White Mudstone with Salmonids; weathered
Cross-bedded Sandstone with roots at base
Siltstone
Gray-brown Sandstone; pebbles suspended in sandstone;
Siltstone
Sandstone with rounded basalt and pumice
Gray Sandstone
Gray Sandstone with basalt pebbles
Gray Siltstone
Tan Siltstone: Coarsening upward
Gray Sandstone: some suspended pebbles
Brown Siltstone-Claystone
Gray sandstone with suspended basalt
Explanation:
10
20
30
40
50
60
70
Lithology:
Sandstone
Cross-bedded Sandstone
Siltstone
Mudstone
Sedimentary Structures:
Basalt Gravels
Root Traces
Tephra
Disconformity

Figure 2.6: Fence diagram of stratigraphic columns from sites g, l, cc, and a of the Fossil Lake Formation.

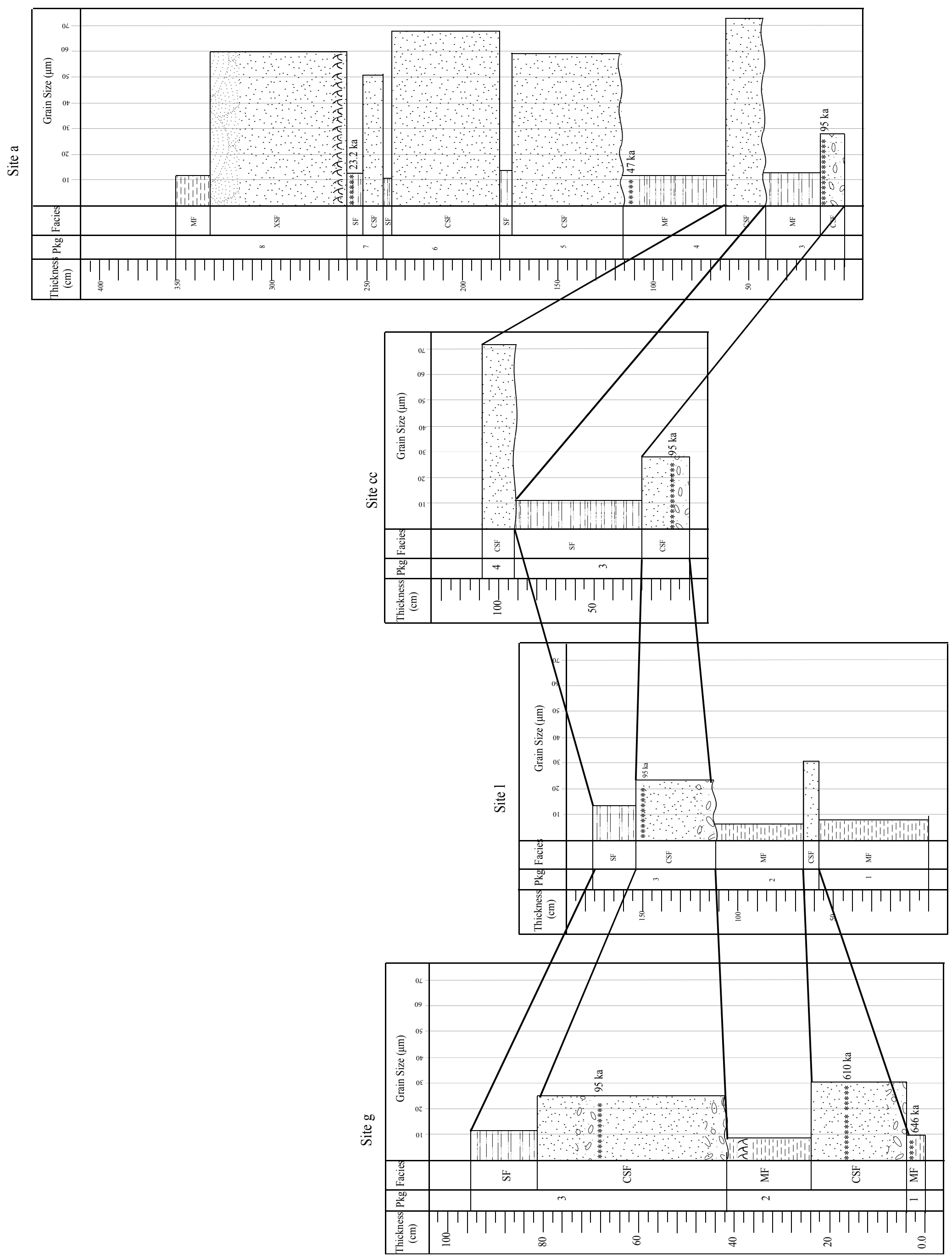
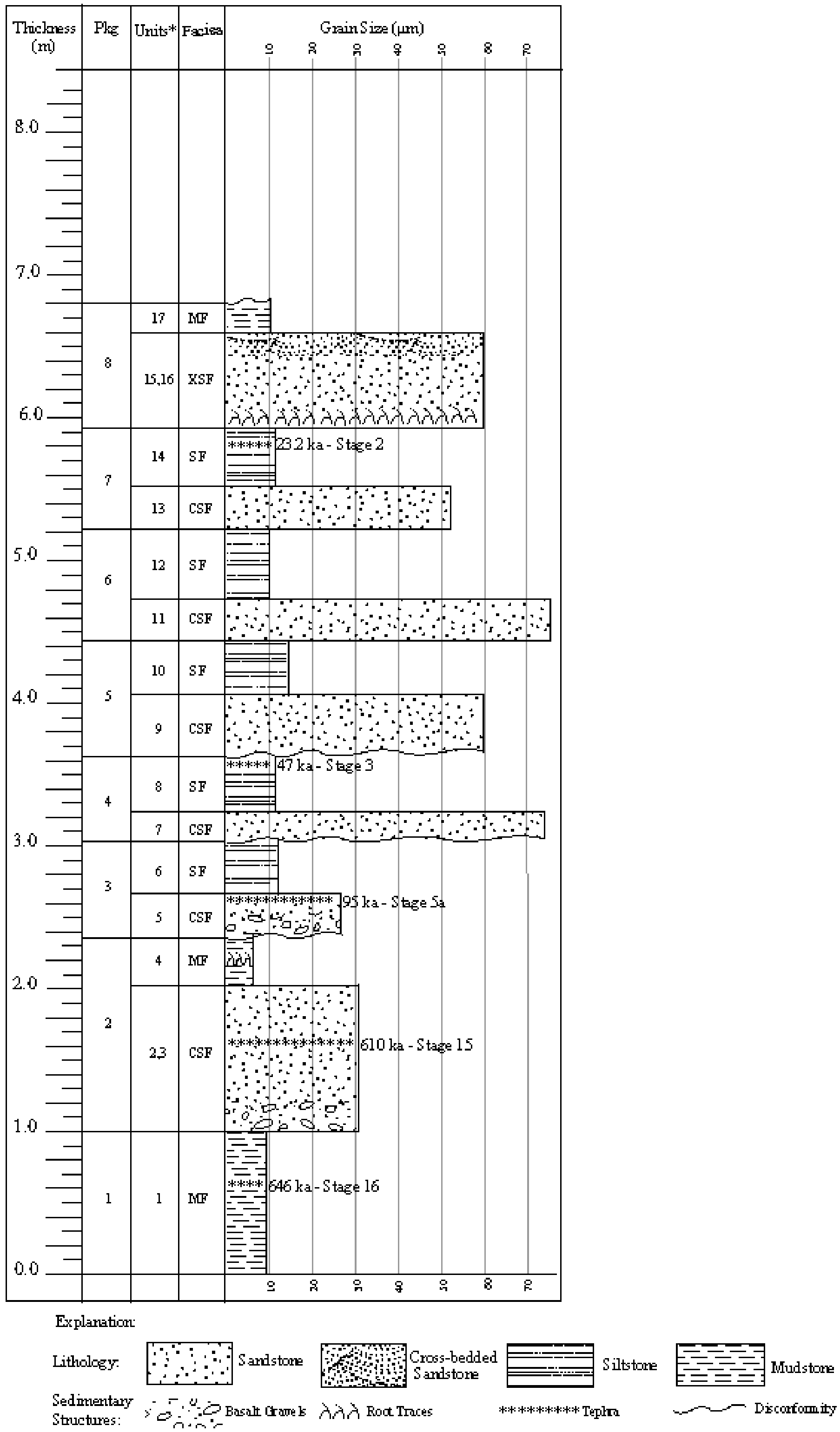

Site a
Site cc
Site l
Site g
Grain Size (µm)
Facies
Pkg
Thickness (cm)
MF
XSF
SF
CSF
23.2 ka
47 ka
95 ka
610 ka
646 ka

Figure 2.7: Composite stratigraphic section of the Fossil Lake Formation, as described herein. A: Conglomeratic Sandstone Facies; B: Cross-bedded Siltstone Facies; C: Siltstone Facies; D: Mudstone Facies. Numbers to the right of tephras indicate their age. Stages refer to Marine Isotope Stages.

Fossil Lake Composite



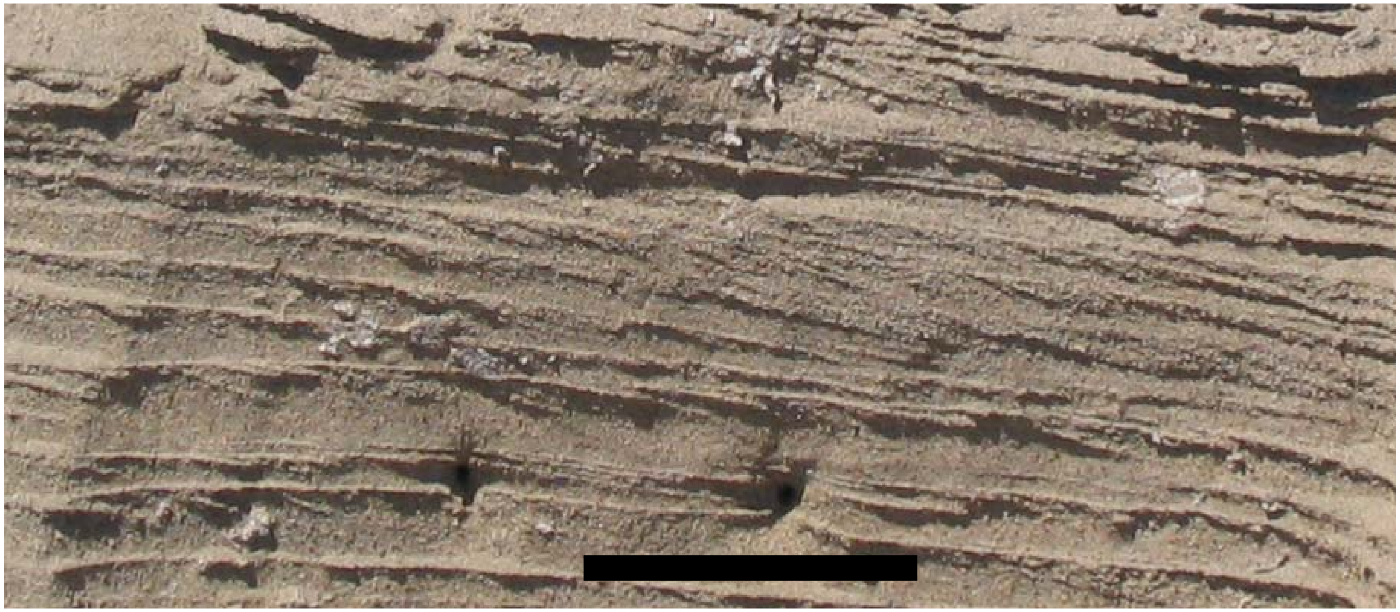


Figure 2.8: Cross-beds and some planar bedding with translatent stratification in the Cross-bedded Siltstone Facies, indicative of eolian deposition at the base of Package 8. Scale bar is 10 cm.

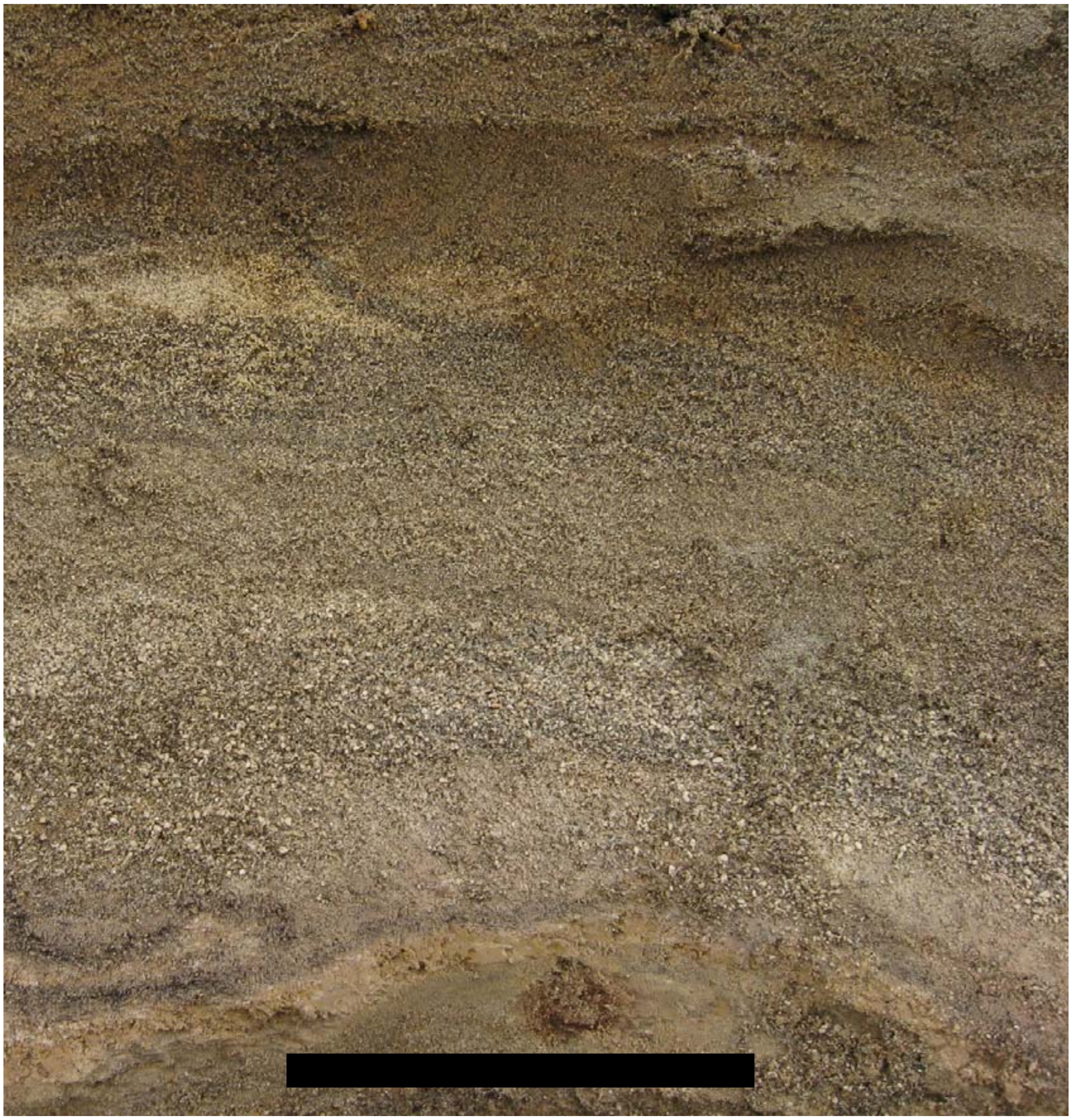


Figure 2.9: Close-up of Tephra C (correlated with the Tulelake T64 tephra, 95 ka) in the Conglomeratic Sandstone/Siltstone Facies of Package 3. Scale bar is 10 cm.

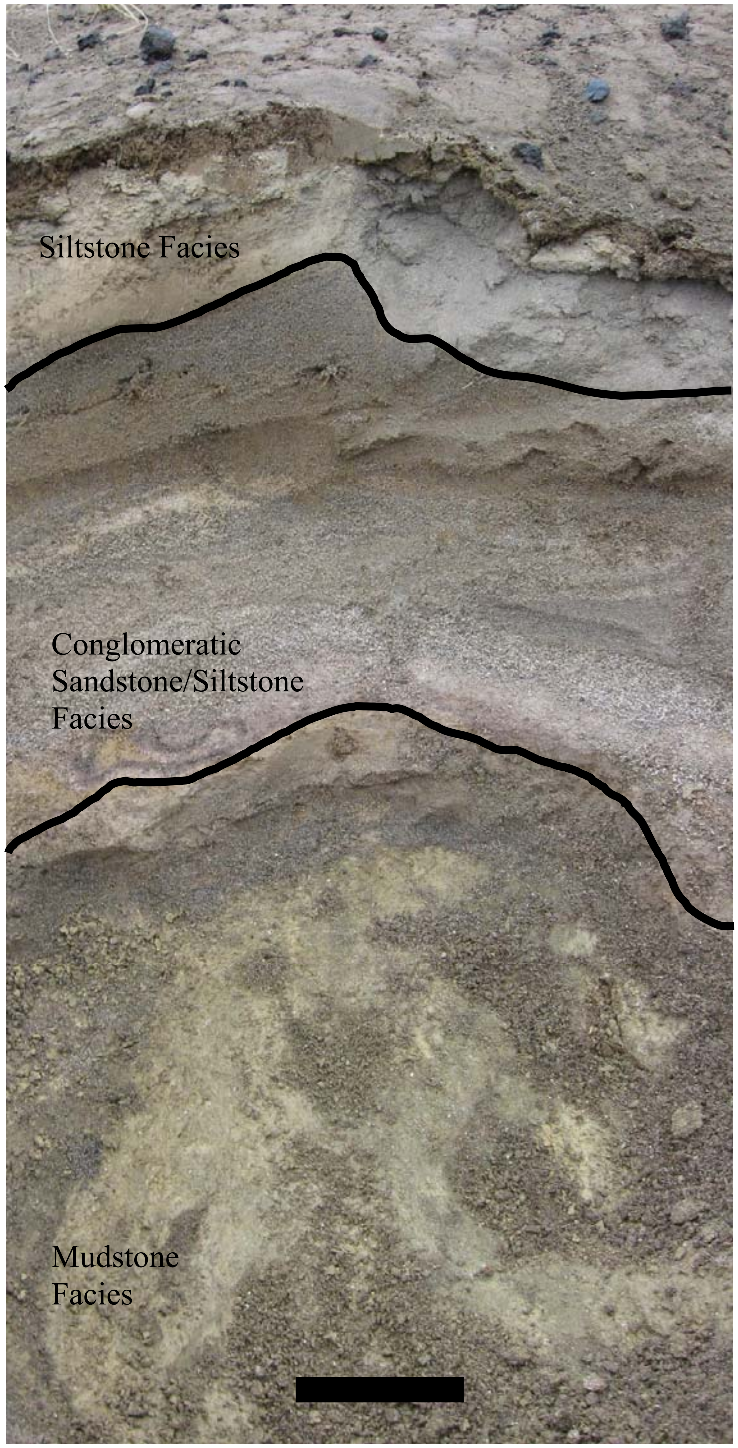


Figure 2.10: Lower packages of Fossil Lake Formation. The basal unit is the Mudstone Facies of Package 2, overlain by the Conglomeratic Sandstone/Siltstone Facies of Package 3, including Tephra C (correlated with the Tulelake T64 Tephra, 95 ka). The top unit is the Siltstone Facies of Package 3. The black lines mark the contact between the facies. Scale bar is 10 cm.

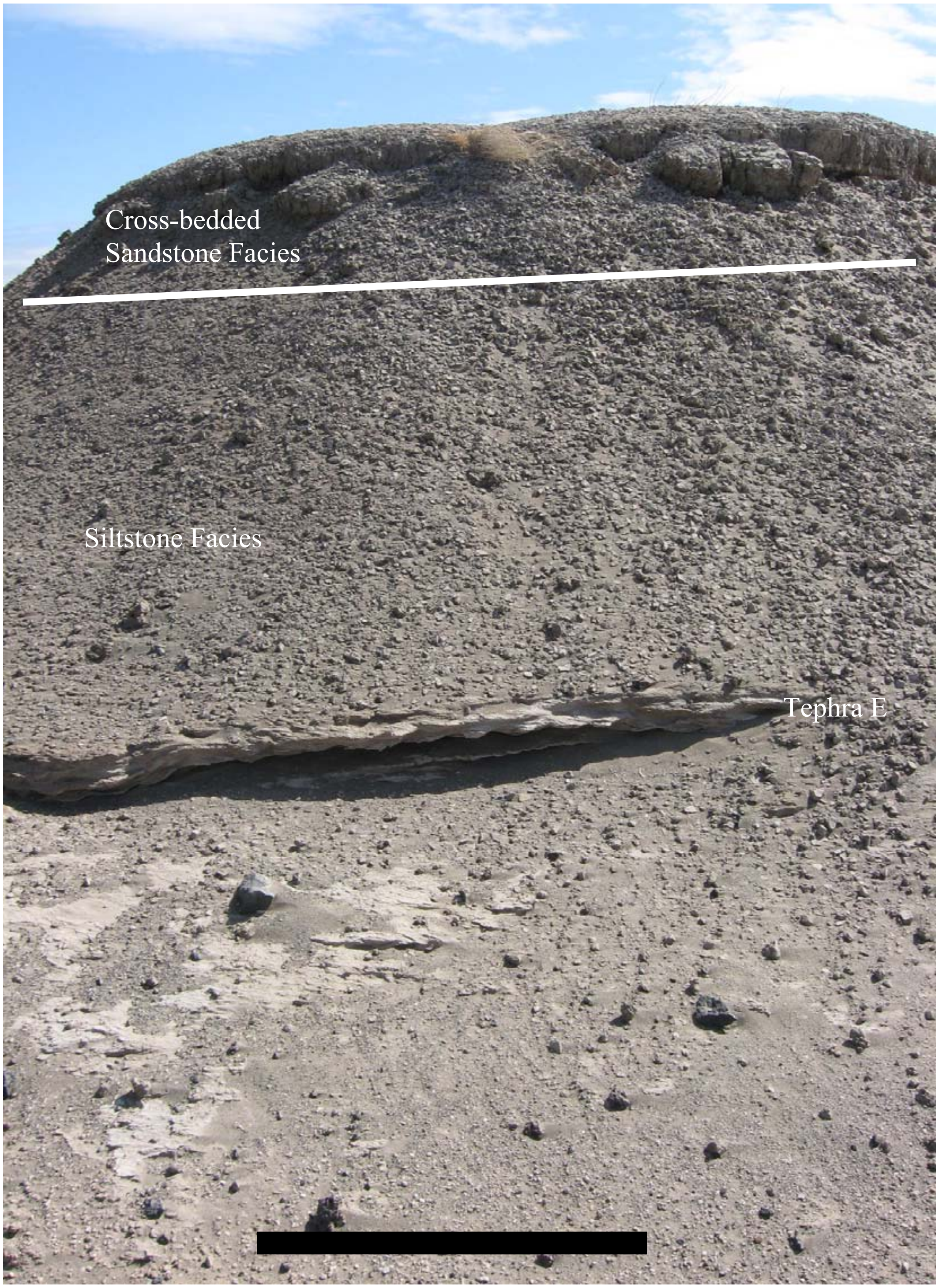


Figure 2.11: Upper packages of the Fossil Lake Formation, including the Cross-bedded Siltstone Facies of Package 8 and tephra E (correlated with the Trego Hot Springs Tephra, 23.3 ka) in the Siltstone Facies of Package 7. The white line marks the contact between the two facies. Scale is 50 cm.

Figure 2.12: Tephra E (correlated with the Trego Hot Springs tephra; 23.2 ka) in the top of Package 7 in the Siltstone Facies. The tephra was waterlain as indicated by the climbing ripples. Scale bar is 10 cm.

Figure 2.13: Distribution of bird genera though Packages 2-4. Bird groups as discussed in text. CSF = Conglomeratic Sandstone/Siltstone Facies; MF = Mudstone Facies, SF = Siltstone Facies.

			Package 2		Package 3		Package 4
			CSF	MF	CSF	SF	CSF
Diving Birds	Podicipedidae	*Aechmophorus*	X	X	X	X	
		Podiceps	X	X	X		
		Podilymbus			X		
	Phalacrocoracide	*Phalacrocorax*	X				
	Anhingidae	*Anhinga*	X	X			
Shallow-water Birds	Anatidae	*Anas*	X	X	X	X	X
		Branta	X	X	X	X	
		Chen	X	X	X		
		Clangula	X				
		Athya	X	X	X		
		Cygna		X			
	Threskiornithidae	*Eudocimus*	X				
	Ardeidae	*Aedea*			X		
	Gruidae	*Grus*		X			
	Rallidae	*Fulica*		X	X		
	Scolopacidae	*Tringa*	X	X			
	Charadriidae	*Charadrius*	X	X			
	Laridae	*Larus*				X	
	Laridae	*Sterna*	X				
Terrestrial Birds	Phasianidae	*Centrocercus*	X	X			
	Falconiformes	*Falco*	X				
	Accipitridae	*Aquila*	X				
	Accipitridae	*Circus*		X			
	Tytonidae	*Otus*		X			
	Corvidae	*Cyanocitta*	X				
	Laniidae	*Lanius*	X				
	Bombycillidae	?*Bombycilla*	X				
	Icteridae	Sturnella	X				
		Xanthocephalus	X				
		?*Euphagus*	X				
	Vireonidae	?*Vireo*	X				
	Totals		23	15	10	4	1

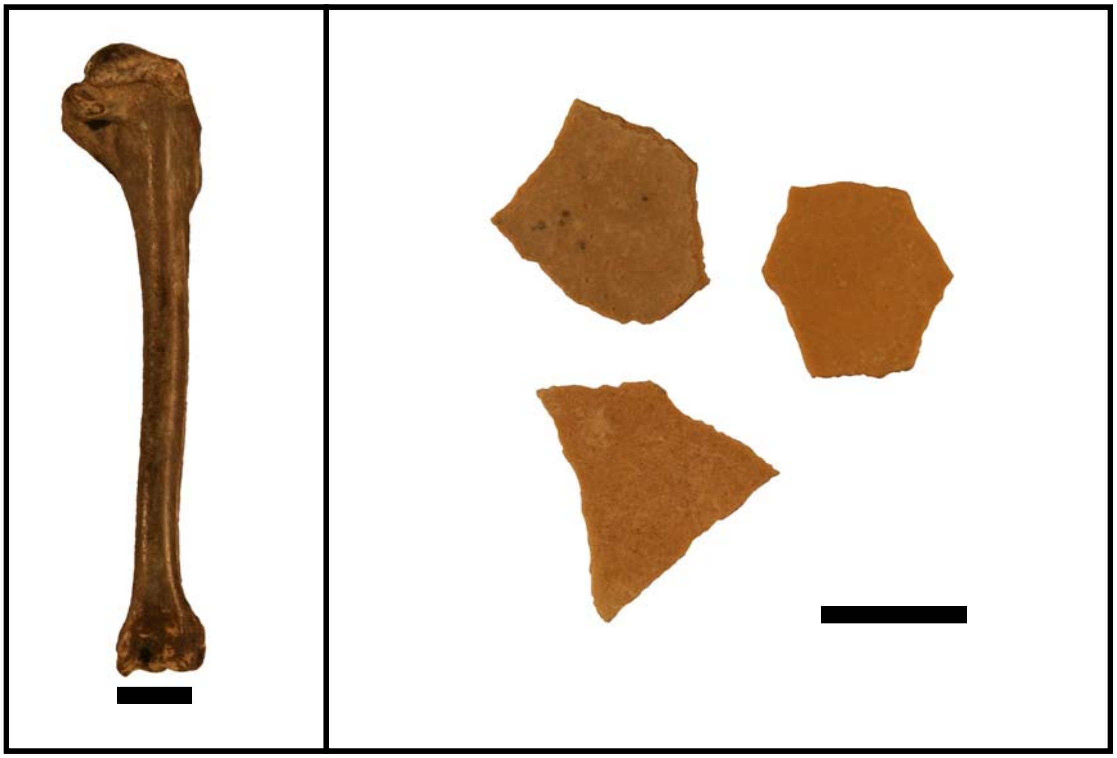


Figure 2.14: Excellent preservation of fossils from the Fossil Lake Formation. Scale bars are 1 cm.

Figure 2.15: Map of Fossil Lake Formation localities. Pie charts represent percentages of bird eco-groups for each facies.

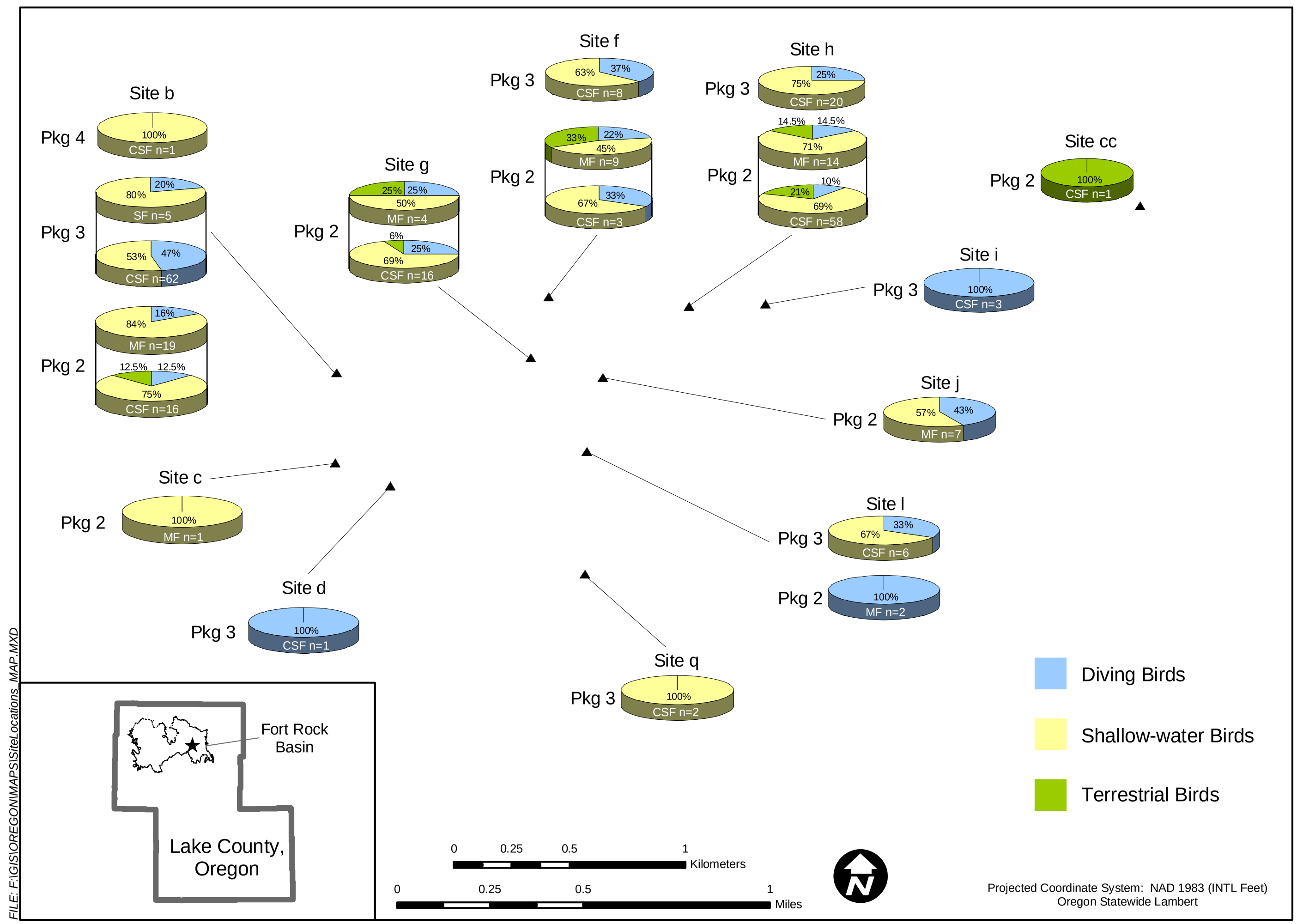
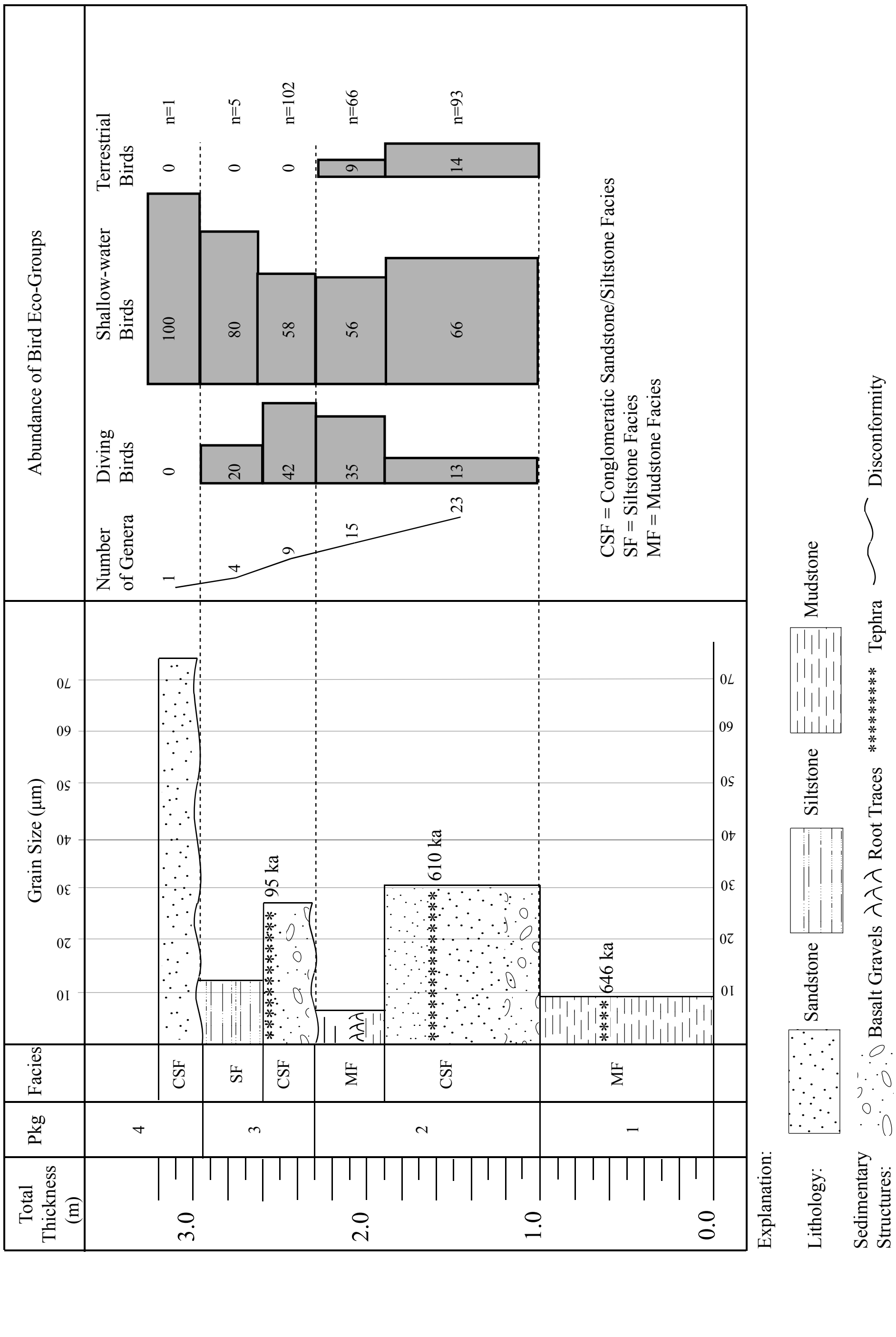
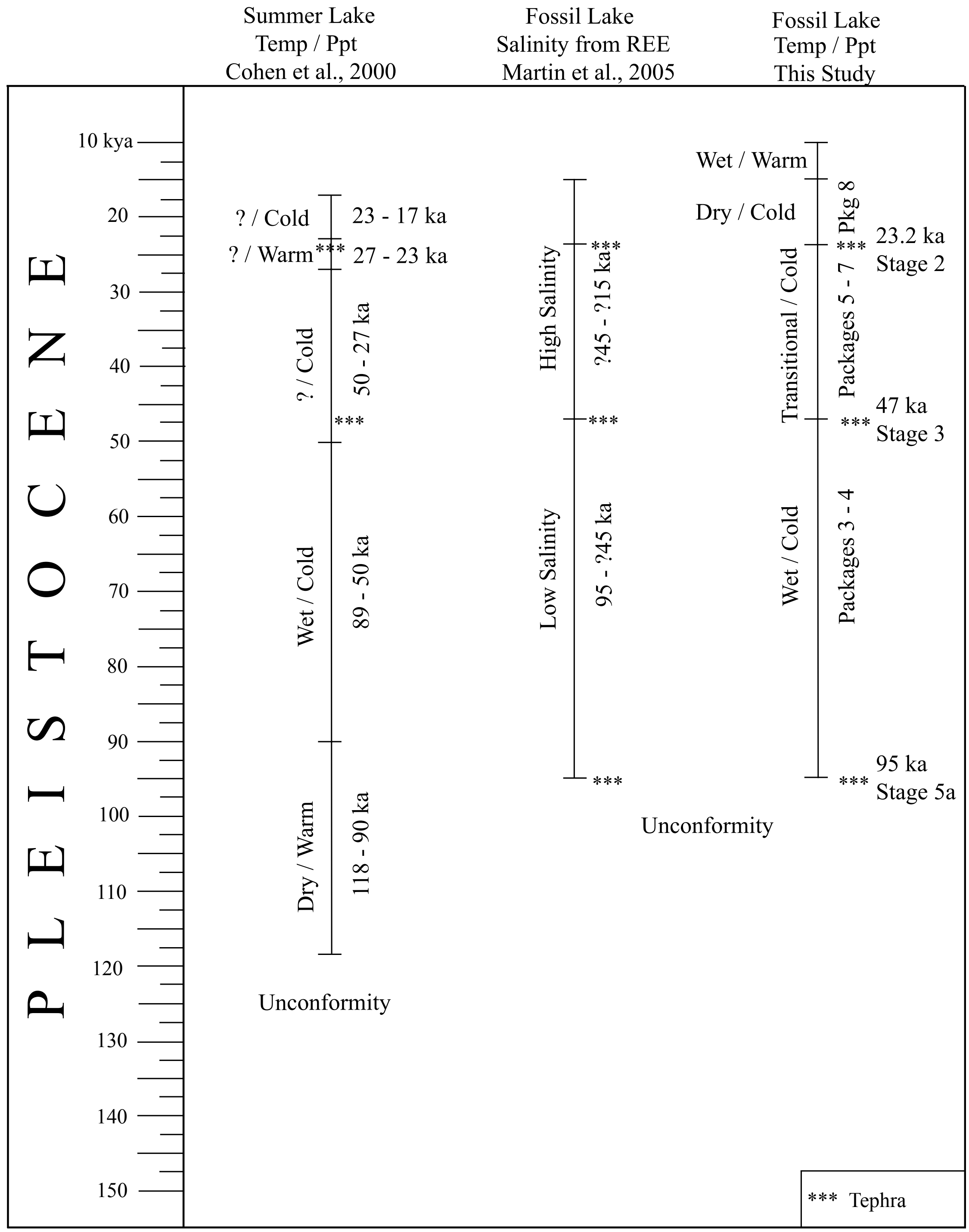

Site b
Pkg 4
100%
CSF n=1
Pkg 3
80%
20%
SF n=5
53%
47%
CSF n=62
Pkg 2
84%
16%
MF n=19
12.5%
12.5%
75%
CSF n=16
Site c
Pkg 2
100%
MF n=1
Site d
Pkg 3
100%
CSF n=1
Site g
Pkg 2
25%
25%
50%
MF n=4
6%
25%
69%
CSF n=16
Site f
Pkg 3
63%
37%
CSF n=8
Pkg 2
33%
22%
45%
MF n=9
67%
33%
CSF n=3
Site h
Pkg 3
75%
25%
CSF n=20
Pkg 2
14.5%
14.5%
71%
MF n=14
10%
21%
69%
CSF n=58
Site cc
Pkg 2
100%
CSF n=1
Site i
Pkg 3
100%
CSF n=3
Site j
Pkg 2
57%
43%
MF n=7
Site l
Pkg 3
67%
33%
CSF n=6
Pkg 2
100%
MF n=2
Site q
Pkg 3
100%
CSF n=2
Diving Birds
Shallow-water Birds
Terrestrial Birds
Fort Rock
Basin
Lake County,
Oregon
0
0.25
0.5
1
Kilometers
0
0.25
0.5
1
Miles
N
Projected Coordinate System: NAD 1983 (INTL Feet)
Oregon Statewide Lambert
FILE: F:\GIS\OREGON\MAPS\SiteLocations_MAP.MXD

Figure 2.16: Summary figure of Fossil Lake Formation facies with generic abundance and eco-group abundances.



Total Thickness (m)
3.0
2.0
1.0
0.0
Pkg
4
3
2
1
Facies
CSF
SF
CSF
MF
CSF
MF
Grain Size (μm)
10
20
30
40
50
60
70
95 ka
610 ka
646 ka
Abundance of Bird Eco-Groups
Number of Genera
1
4
9
15
23
Diving Birds
0
20
42
35
13
Shallow-water Birds
100
80
58
56
66
Terrestrial Birds
0
0
0
9
14
n=1
n=5
n=102
n=66
n=93
CSF = Conglomeratic Sandstone/Siltstone Facies
SF = Siltstone Facies
MF = Mudstone Facies
Explanation:
Lithology:
Sandstone
Siltstone
Mudstone
Sedimentary Structures:
Basalt Gravels
λλλ Root Traces
********* Tephra
Disconformity

Figure 2.17: Inferred temperature and precipitation levels determined from previous workers (Cohen et al., 2000; Martin et al., 2005), as well as lithostratigraphic data in this study. Temp = Temperature; Ppt = Precipitation; REE = Rare earth element geochemistry data.



Summer Lake
Temp / Ppt
Cohen et al., 2000
Fossil Lake
Salinity from REE
Martin et al., 2005
Fossil Lake
Temp / Ppt
This Study
P L E I S T O C E N E
10 kya
20
30
40
50
60
70
80
90
100
110
120
130
140
150
? / Cold
23 - 17 ka
? / Warm
***
27 - 23 ka
? / Cold
50 - 27 ka
***
Wet / Cold
89 - 50 ka
Dry / Warm
118 - 90 ka
Unconformity
High Salinity
***
?45 - ?15 ka
***
Low Salinity
95 - ?45 ka
***
Unconformity
Wet / Warm
Dry / Cold
Pkg 8
***
23.2 ka
Stage 2
Transitional / Cold
Packages 5 - 7
***
47 ka
Stage 3
Wet / Cold
Packages 3 - 4
***
95 ka
Stage 5a
*** Tephra

Plate 2.1: Galliformes
A: SDSM 28894: Galliformes, Distal tibiotarsus, cranial view.
B: SDSM 31957: *Centrocercus urophasianus*, Digit 2, phalanx 1.
C: SDSM 74807: *Centrocercus urophasianus*, Synsacrum, dorsal view.
D: SDSM 29523: *Centrocercus urophasianus*, Proximal femur, cranial view.
E: SDMS 30177: *Centrocercus urophasianus*, Proximal tarsometarsus, dorsal view.
All scale bars = 1 cm.

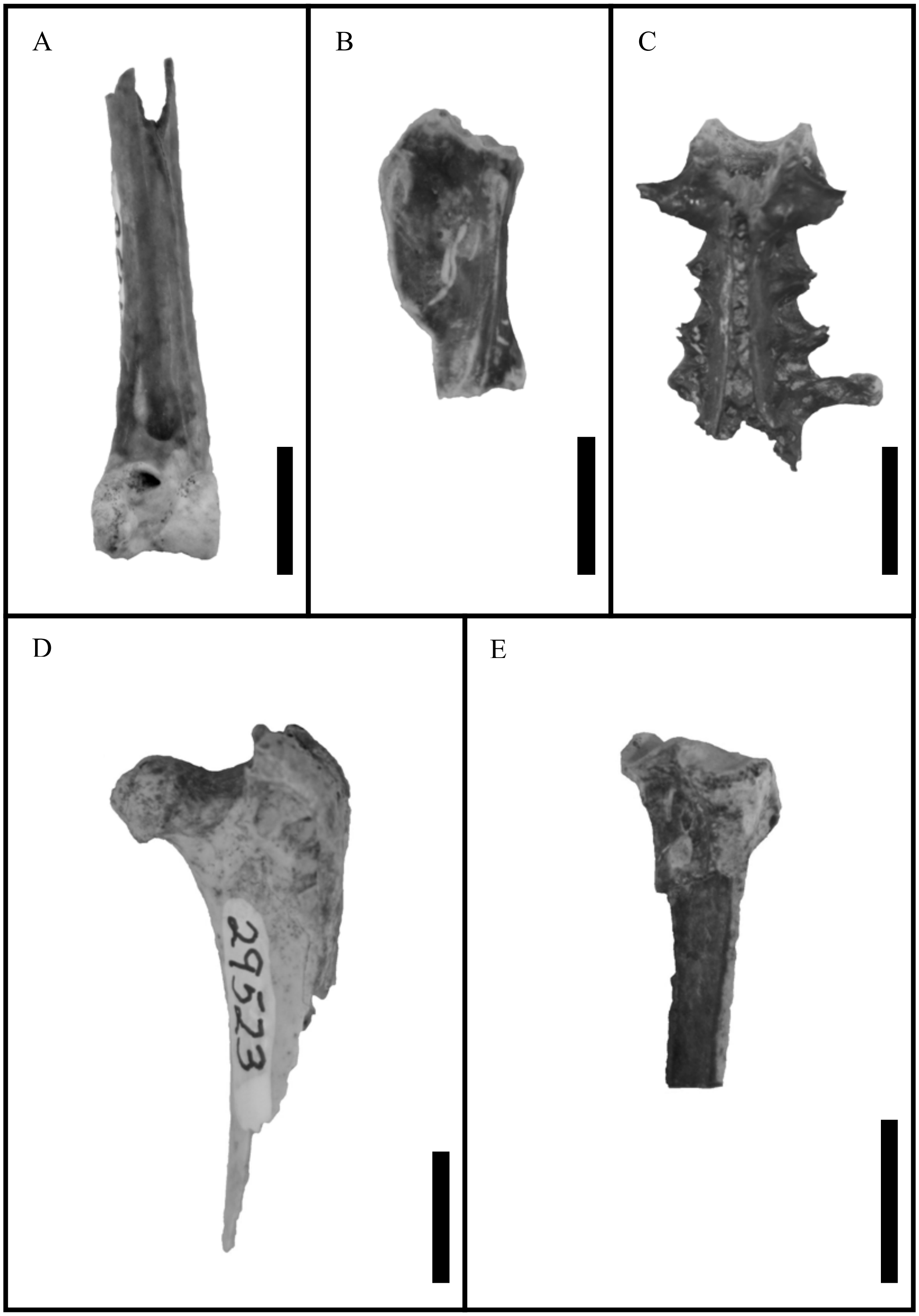

A
B
C
D
E
29523

Plate 2.2: Anseriformes
A: SDSM 74945: *Anas acuta*, Proximal ulna, caudal view.
B: SDSM 74945: *Anas acuta*, Distal ulna, caudal view.
C: SDSM 74876: *Anas americana*, Basicranium, dorsal view.
D: SDSM 31179: *Anas americana*, Sternum, ventral view.
E: SDSM 31431: *Anas americana*, Coracoid, dorsal view.
F: SDSM 31950: *Anas americana*, Proximal sternum, costal view.
G: SDSM 74931: *Anas americana*, Proximal humerus, cranial view.
All scale bars = 1 cm.

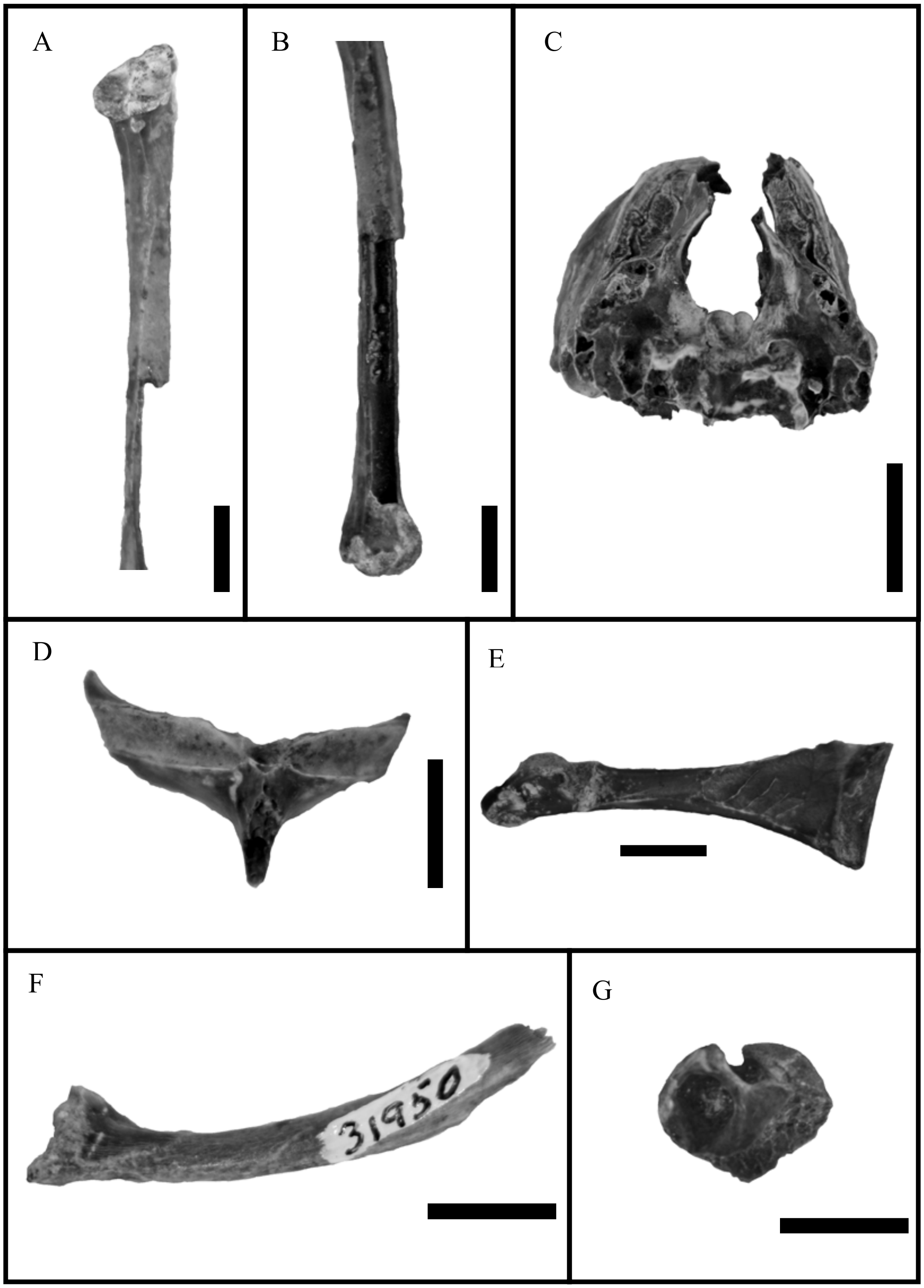

A
B
C
D
E
F
31950
G

Plate 2.3: Aneriformes
A: SDSM 33056: *Anas americana*, Proximal ulna, caudal view.
B: SDSM 31277: *Anas americana*, Carpometacarpus, ventral view.
C: SDSM 30164: *Anas americana*, Distal femur, caudal view.
D: SDSM 30173: *Anas americana*, Distal tibiotarsus, cranial view.
E: SDSM 30281: *Anas americana*, Tarsometatarsus, plantar view.
All scale bars = 1 cm.


A
33056
B
C
D
E

Plate 2.4: Anseriformes
A: SDSM 30109: *Anas clypeata*, Coracoid, dorsal view.
B: SDSM 30587: *Anas clypeata*, Proximal scapula, costal view.
C: SDSM 32969: *Anas clypeata*, Distal ulna, caudal view.
D: SDSM 28887: *Anas clypeata*, Carpometacarpus, dorsal view.
E: SDSM 30562a: *Anas clypeata*, Distal radius, caudal view.
F: SDSM 30880: *Anas clypeata*, Distal tibiotarsus, cranial view.
All scale bars = 1 cm.

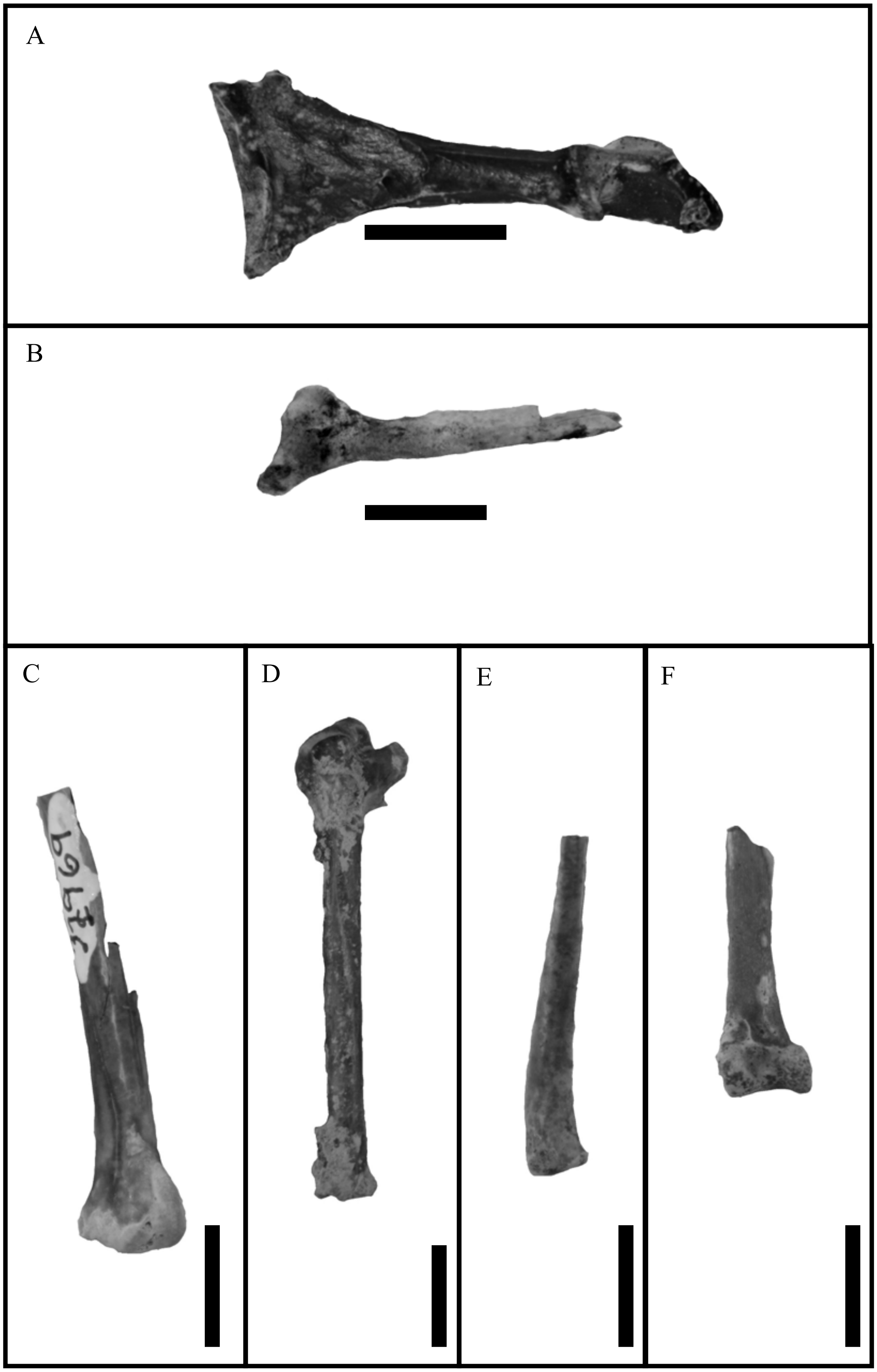

A
B
C
D
E
F

Plate 2.5: Anseriformes
A: SDSM 28269: *Anas crecca*, Proximal coracoid, dorsal view.
B: SDSM 29139: *Anas crecca*, Proximal humerus, cranial view.
C: SDSM 31197: *Anas crecca*, Distal ulna, caudal view.
D: SDSM 30276: *Anas crecca*, Proximal carpometacarpus, ventral view.
E: SDSM 30567: *Anas crecca*, Tarsometatarsus, dorsal view.
F: SDSM 30567: *Anas crecca*, Tarsometatarsus, plantar view.
All scale bars = 1 cm.


A
B
C
31197
D
E
F

Plate 2.6: Anseriformes
A: SDSM 74905: *Anas platyrhynchos*, Sternum, costal view.
B: SDSM 31288: *Anas platyrhynchos*, Distal coracoid, dorsal view.
C: SDSM 30863: *Anas platyrhynchos*, Proximal scapula, costal view.
D: SDSM 30272: *Anas platyrhynchos*, Furcular fragment.
E: SDSM 75138: *Anas platyrhynchos*, Humerus, caudal view.
F: SDSM 75138: *Anas platyrhynchos*, Humerus, cranial view.

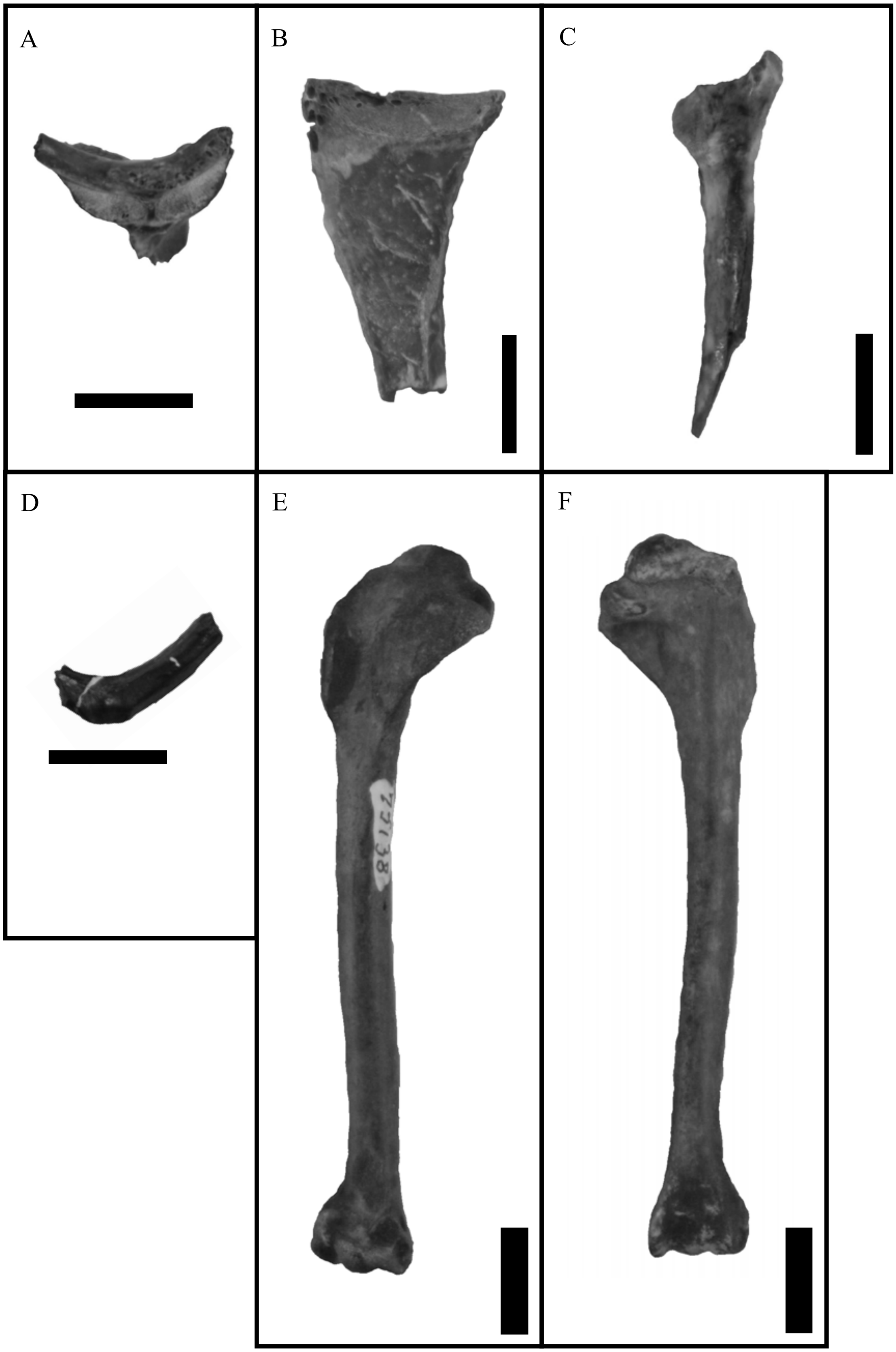

A
B
C
D
E
F
251138

Plate 2.7: Anseriformes
A: SDSM 30561: *Anas platyrhynchos*, Proximal radius, caudal view.
B: SDSM 74818: *Anas platyrhynchos*, Proximal carpometacarpus, ventral view.
C: SDSM 29189a: *Anas platyrhynchos*, Distal tibiotarsus, cranial view.
D: SDSM 30179: *Anas platyrhynchos*, Distal tarsometatarsus, dorsal view.
All scale bars = 1 cm.

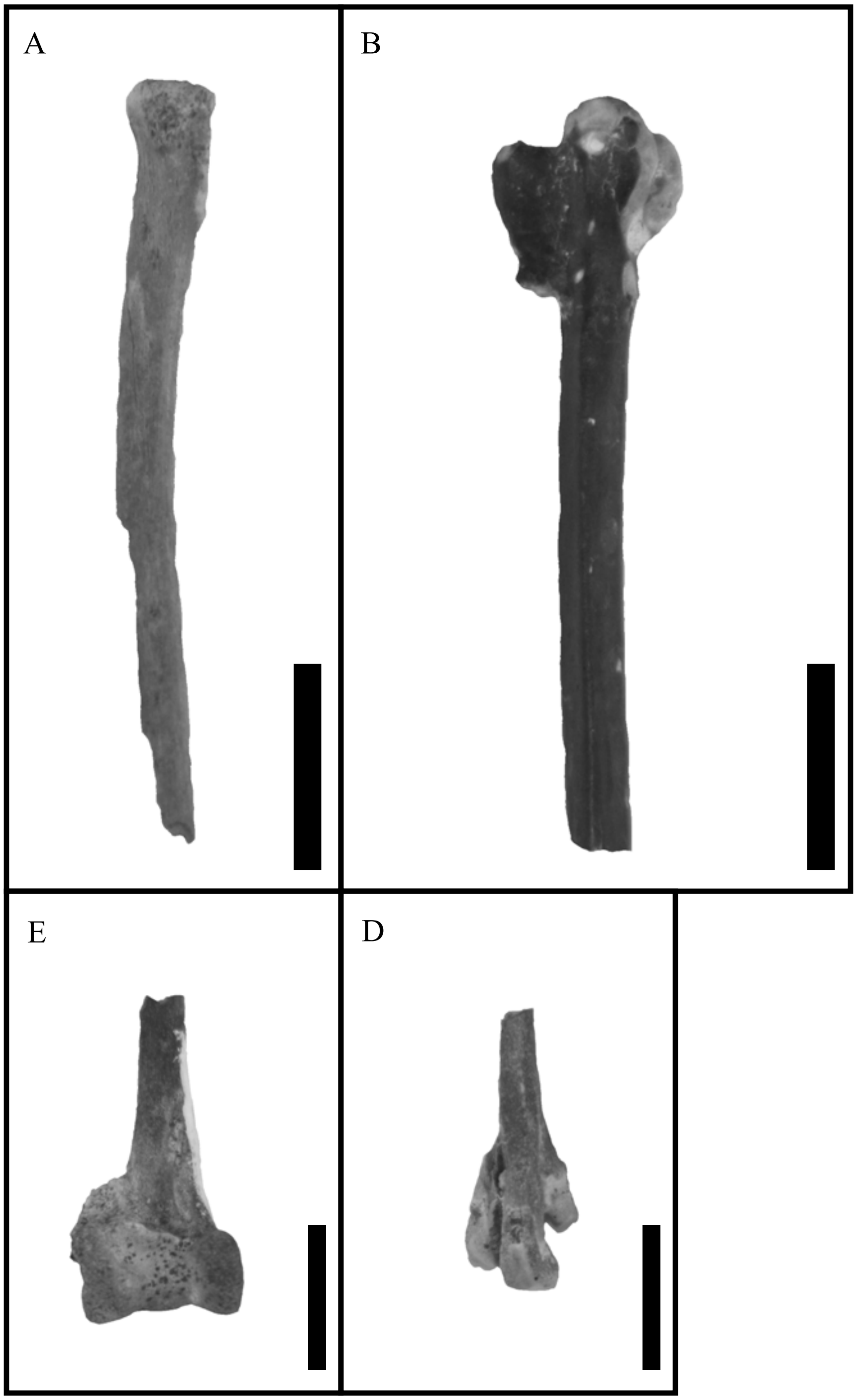

A
B
E
D

Plate 2.8: Anseriformes
A: SDSM 31326: *Aythya affinis*, Tarsometatarsus, dorsal view.
B: SDSM 31336: *Aythya affinis*, Tarsometatarsus, plantar view.
C: SDSM 74915: *Branta bernicla*, Coracoid, dorsal view.
D: SDSM 30128: *Branta bernicla*, Furcula.
E: SDSM 31320: *Branta bernicla*, Distal tibiotarsus, cranial view.
All scale bars = 1 cm.

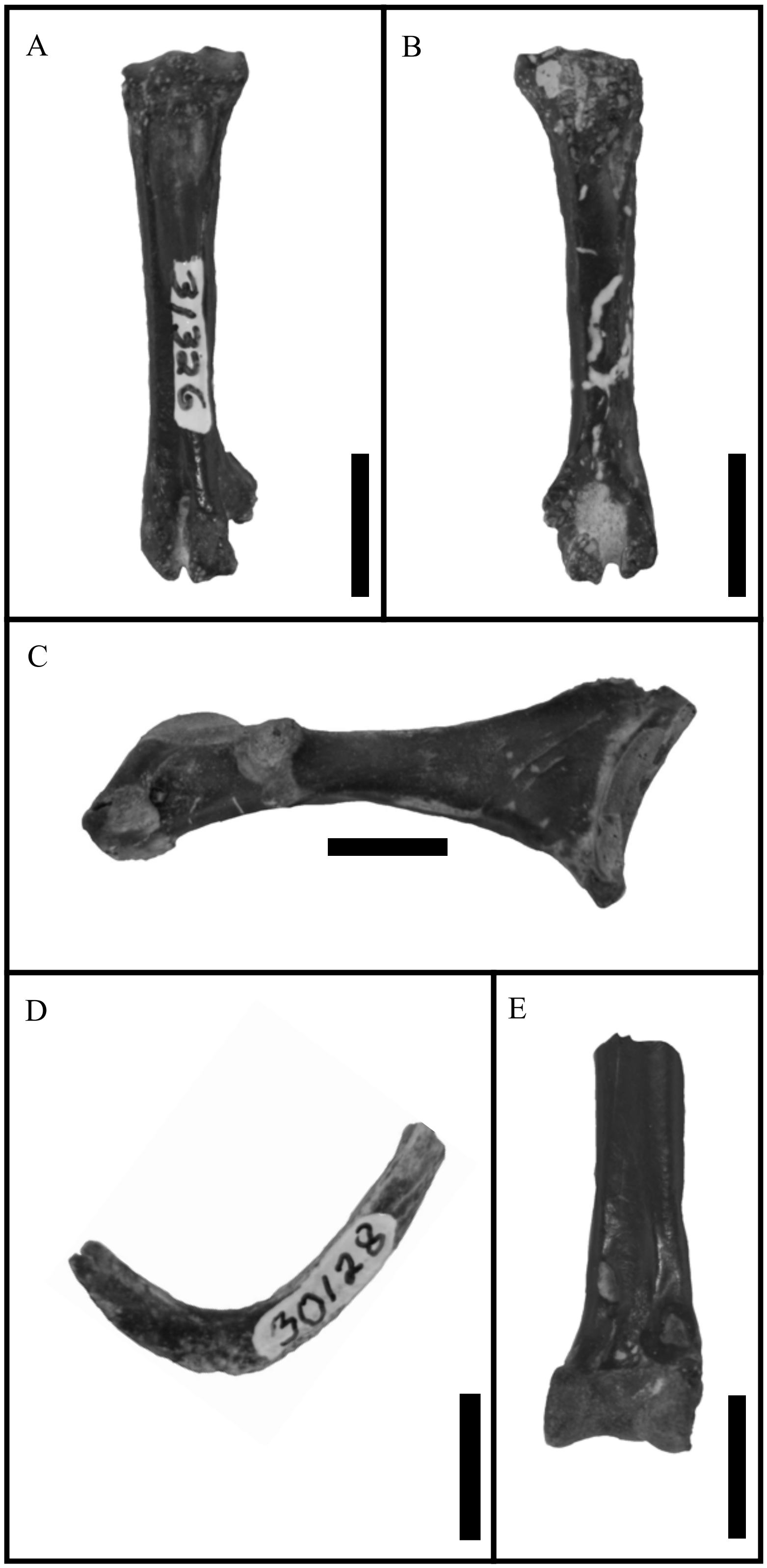

A
31326
B
C
D
30128
E

Plate 2.9: Anseriformes
A: SDSM 30860: *Branta canadensis*, Proximal coracoid, dorsal view.
B: SDSM 31436: *Branta canadensis*, Proximal scapula, lateral view.
C: SDSM 29117: *Branta canadensis*, Furcula, fragment.
All scale bars = 1 cm


A
B
31436
C

Plate 2.10: Anseriformes
A: SDSM 31287: *Chen rossi*, Proximal coracoid, dorsal view.
B: SDSM 31181: *Chen rossi*, Proximal scapula, lateral view.
C: SDSM 28659: *Chen rossi*, Distal humerus, caudal view.
D: SDSM 74972: *Chen rossi*, Distal tibiotarsus, dorsal view.
E: SDSM 30557: *Clangula hyemalis*, Furcula, fragment.
All scale bars = 1 cm.

A
B
C
D
E

Plate 2.11: Anseriformes
A: SDSM 74965: *Mergus serrator*, Tibiotarsus, caudal view.
B: SDSM 31212: *Cygnus olor*, Trochlea of tarsometatarsus.
All scale bars = 1 cm.


A
SDSM 74965
B
31212

Plate 2.12: Podicipediformes
A: SDSM 31186: *Aechmophorus occidentalis*, Coracoid, dorsal view.
B: SDSM 33047: *Aechmophorus occidentalis*, Proximal scapula, lateral view.
C: SDSM 30129: *Aechmophorus occidentalis*, Furcular fragment.
D: SDSM 75153: *Aechmophorus occidentalis*, Distal humerus, caudal view.
E: SDSM 33057: *Aechmophorus occidentalis*, Distal carpometacarpus, ventral view.
All scale bars = 1 cm.

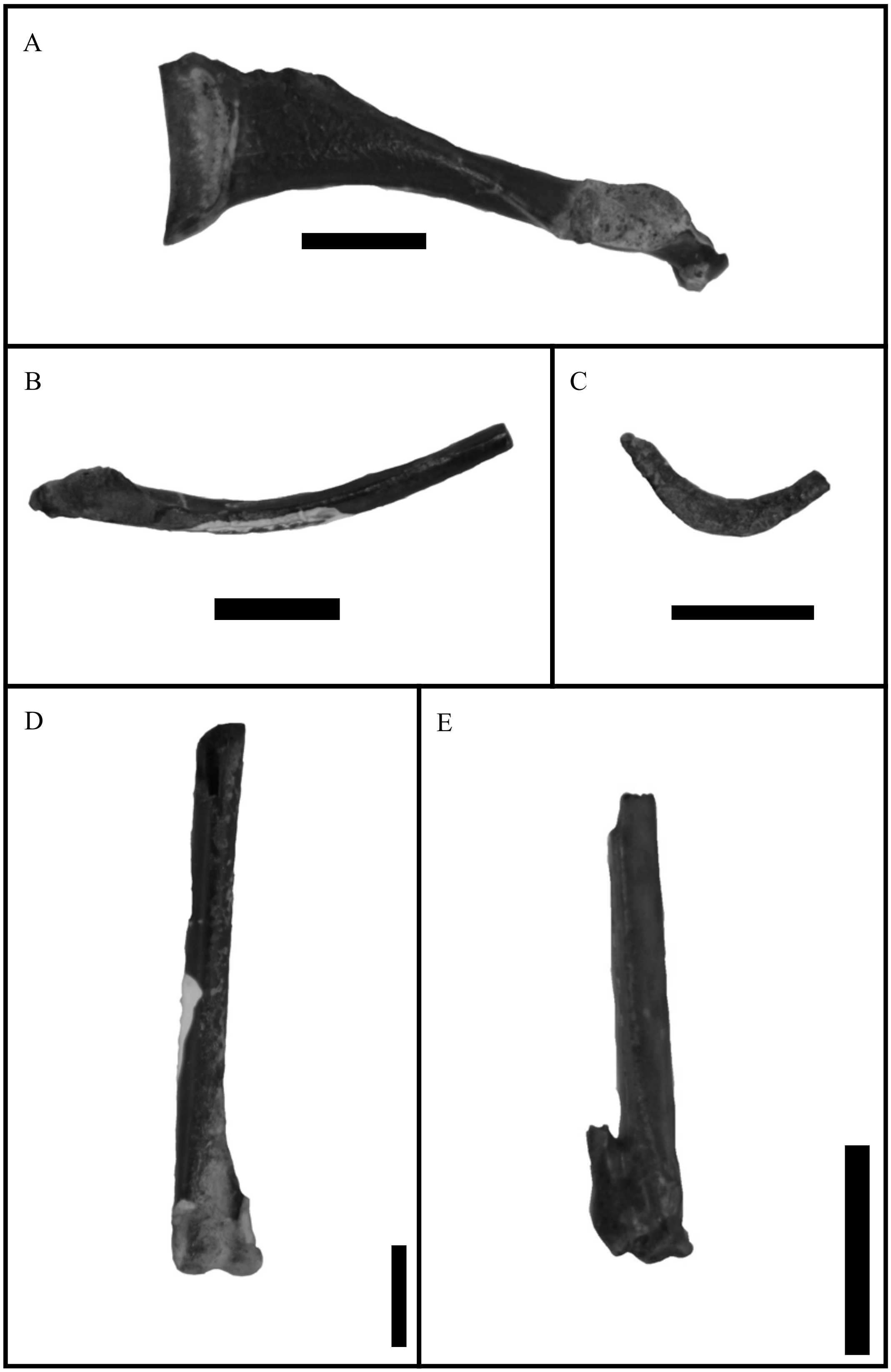

A
B
C
D
E

Plate 2.13: Podicipediformes
A: SDSM 29176: *Aechmophorus occidentalis*, Femur, caudal view.
B: SDSM 75169: *Aechmophorus occidentalis*, Distal tibiotarsus, caudal view.
C: SDSM 74803: *Podiceps nigricollis*, Proximal coracoid, dorsal view.
D: SDSM 31290: *Podiceps nigricollis*, Distal humerus, caudal view.
E: SDSM 74918: *Podilymbus podiceps*, Coracoid, dorsal view.
All scale bars = 1 cm.


A
B
C
D
E

Plate 2.14: Pelecaniformes (A-B); Ciconiiformes (C)
A: SDSM 75162: *Phalacrocorax auritus*, Synsacrum, dorsal view.
B: SDSM 74821: *Phalacrocorax auritus*, Tarsometatarsus, plantar view.
C: SDSM 30149: *Anhinga anhinga*, Distal ulna, caudal view.
D: SDSM 30133: *Eudocimus ruber*, Proximal humerus, cranial view.
All scale bars = 1 cm.

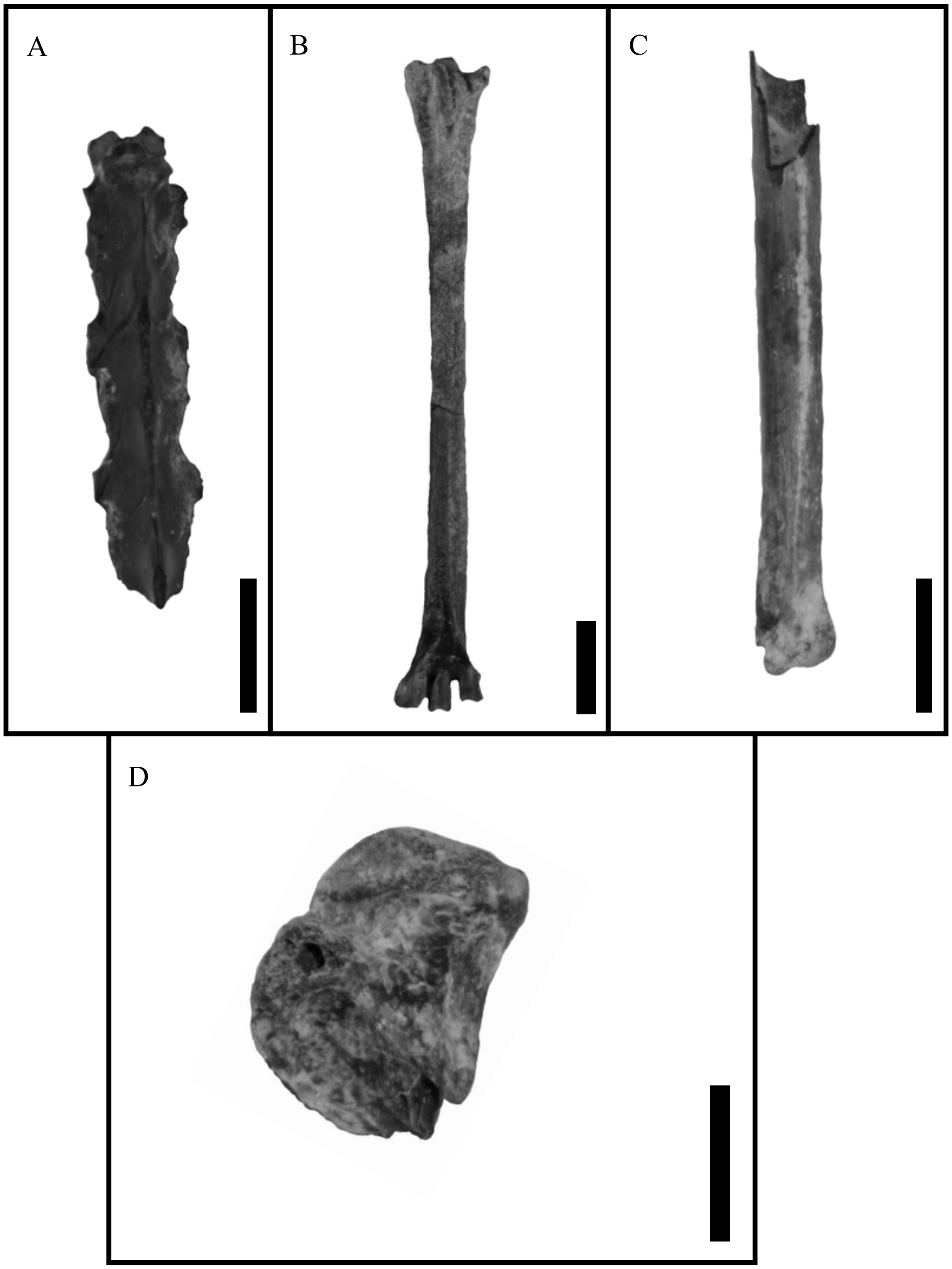

A
B
C
D

Plate 2.15: Ardeiformes
A: SDSM 74907: *Ardea herodias*, Sternum, costal view.
B: SDSM 32970: *Ardea herodias*, Proximal carpometacarpus, dorsal view.
C: SDSM 32970: *Ardea herodias*, Digit 2, phalanx 1.
D: SDSM 74988: *Ardea herodias*, Distal tarsometatarsus, dorsal view.
All scale bars = 1 cm.


A
B
C
32970
D

Plate 2.16: Ralliformes
A: SDSM 31193: *Fulica* sp., Proximal ulna, caudal view.
B: SDSM 30270: *Fulica americana*, Coracoid, dorsal view.
C: SDSM 30864: *Fulica americana*, Proximal scapula, costal view.
D: SDSM 30871: *Fulica americana*, Distal humerus, caudal view.
E: SDSM 31208: *Fulica americana*, Proximal tarsometatarsus, plantar view.
All scale bars = 1 cm.

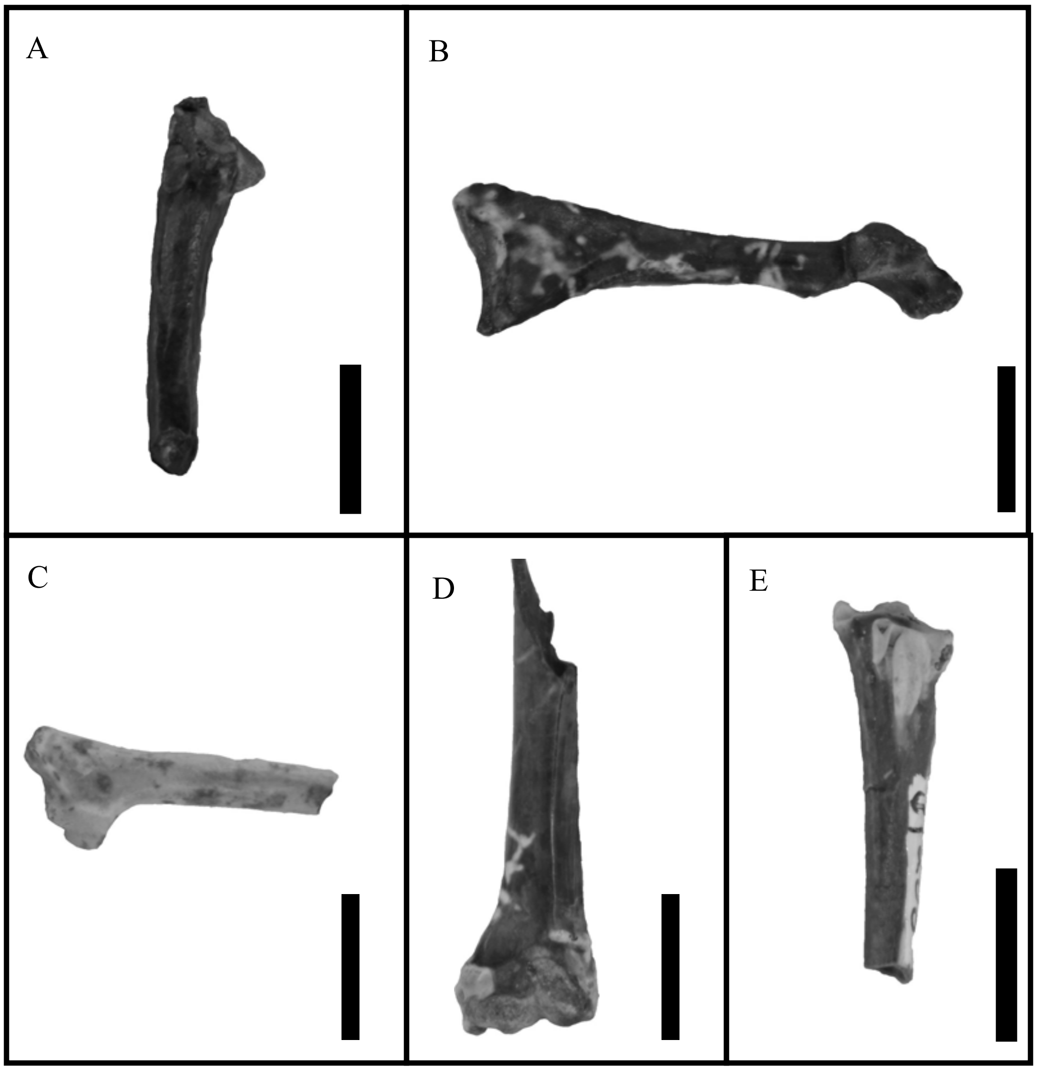

A
B
C
D
E

Plate 2.17: Charadriiformes
A: SDSM 30865: *Tringa* sp, Scapula, costal view.
B: SDSM 30171: *Tringa* sp, Proximal tibiotarsus, caudal view.
C: SDSM 74772: *Tringa melanoleauca*, Carpometacarpus, ventral view.
D: SDSM 30559: *Charadrius alexandrius*, Humerus, caudal view.
Scale bars = 1 cm.

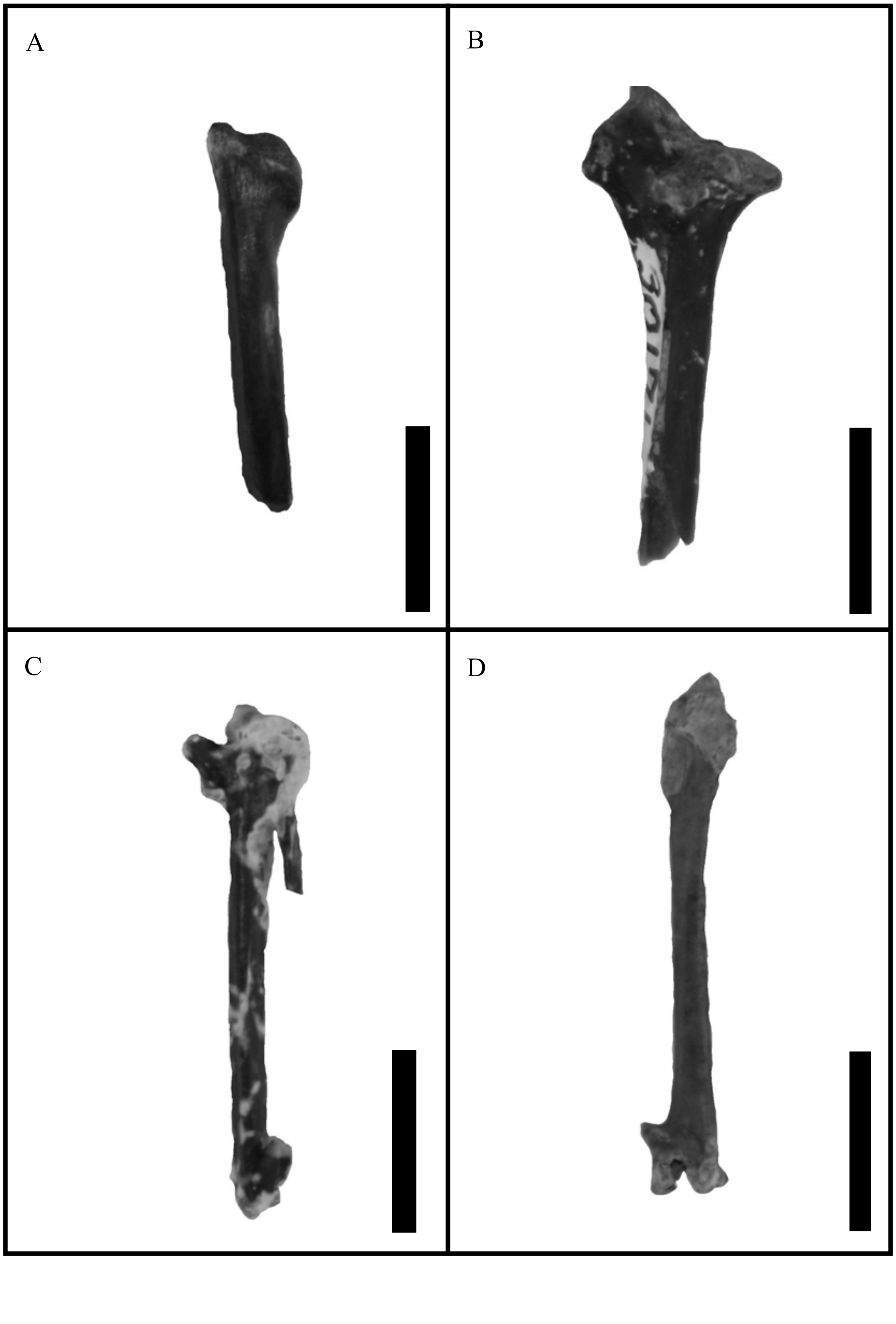

A
B
C
D

Plate 2.18: Charadriiformes (A-C); Falconiformes (D)
A: SDSM 69628: *Larus occidentalis*, caudal view.
B: SDSM 30146: *Sterna forsteri*, Proximal radius, cranial view.
C: SDSM 29956: *Uria* sp., Proximal humerus, cranial view.
D: SDSM 30150: *Falco* sp., Distal humerus, caudal view.
All scale bars = 1 cm.

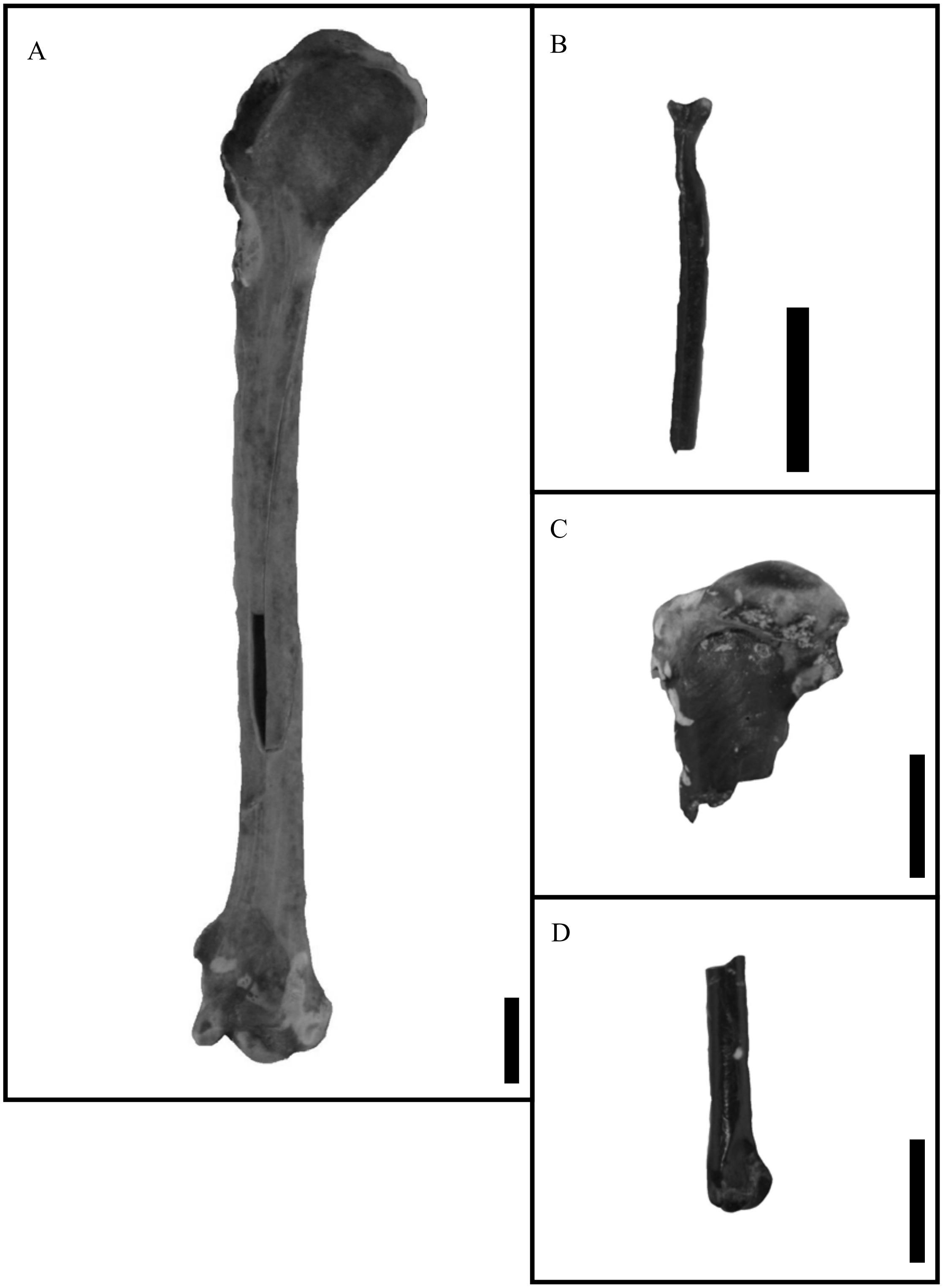

A
B
C
D

Plate 2.19: Falconiformes
A: SDSM 74919: Accipitridae, Coracoid, dorsal view.
B: SDSM 30084: Accipitridae, Ungual.
C: SDSM 30142: *Aquila chrysaetos*, Proximal radius, caudal view.
D: SDSM 31956: *Circus cyaneus*, Distal carpometacarpus, ventral view.
All scale bars = 1 cm.

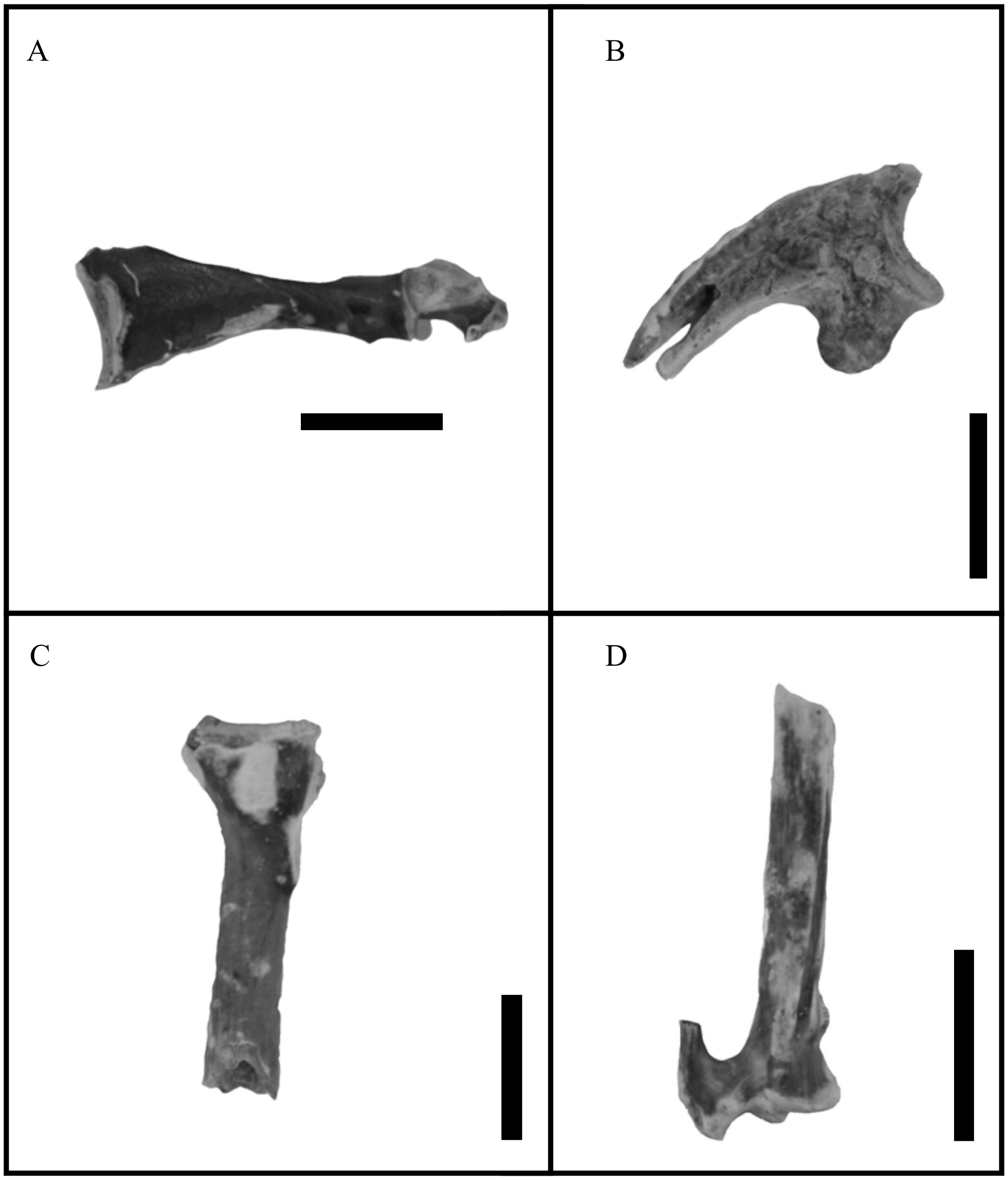

A
B
C
D

Plate 2.20: Strigiformes (A); Passeriformes (B-D)
A: SDSM 74799: *Otus* ?*kennecotti*, Sternum, ventral view.
B: SDSM 30166: *Cyanocitta cristata*, Carpometacarpus, ventral view.
C: SDSM 30154: *Lanius ludovicianus*, Proximal ulna, caudal view.
D: SDSM 30563: ?*Bombycilla cedorum*, Proximal ulna, caudal view.
E: SDSM 30120: Fringillidae, Coracoid, dorsal view.

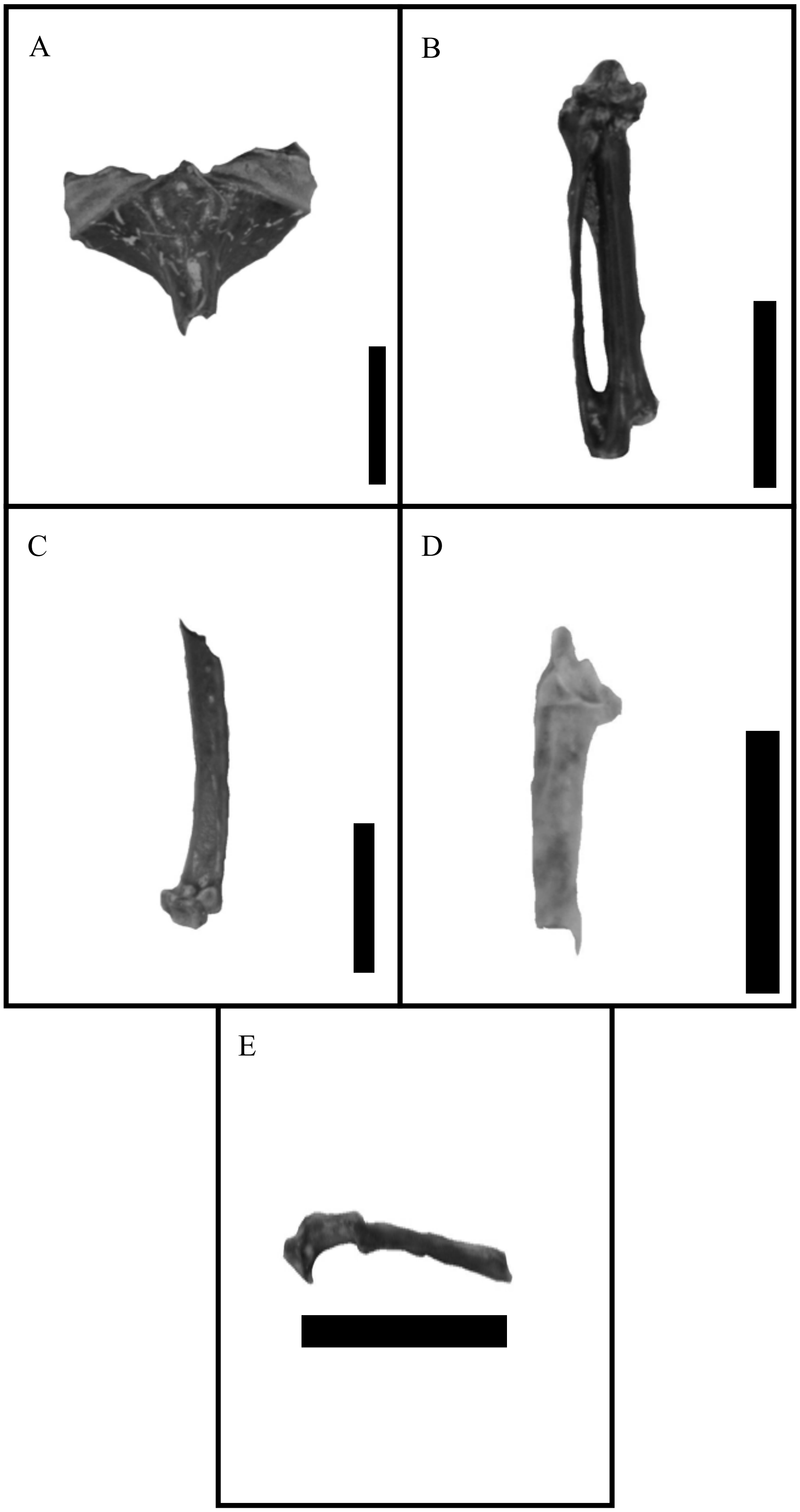
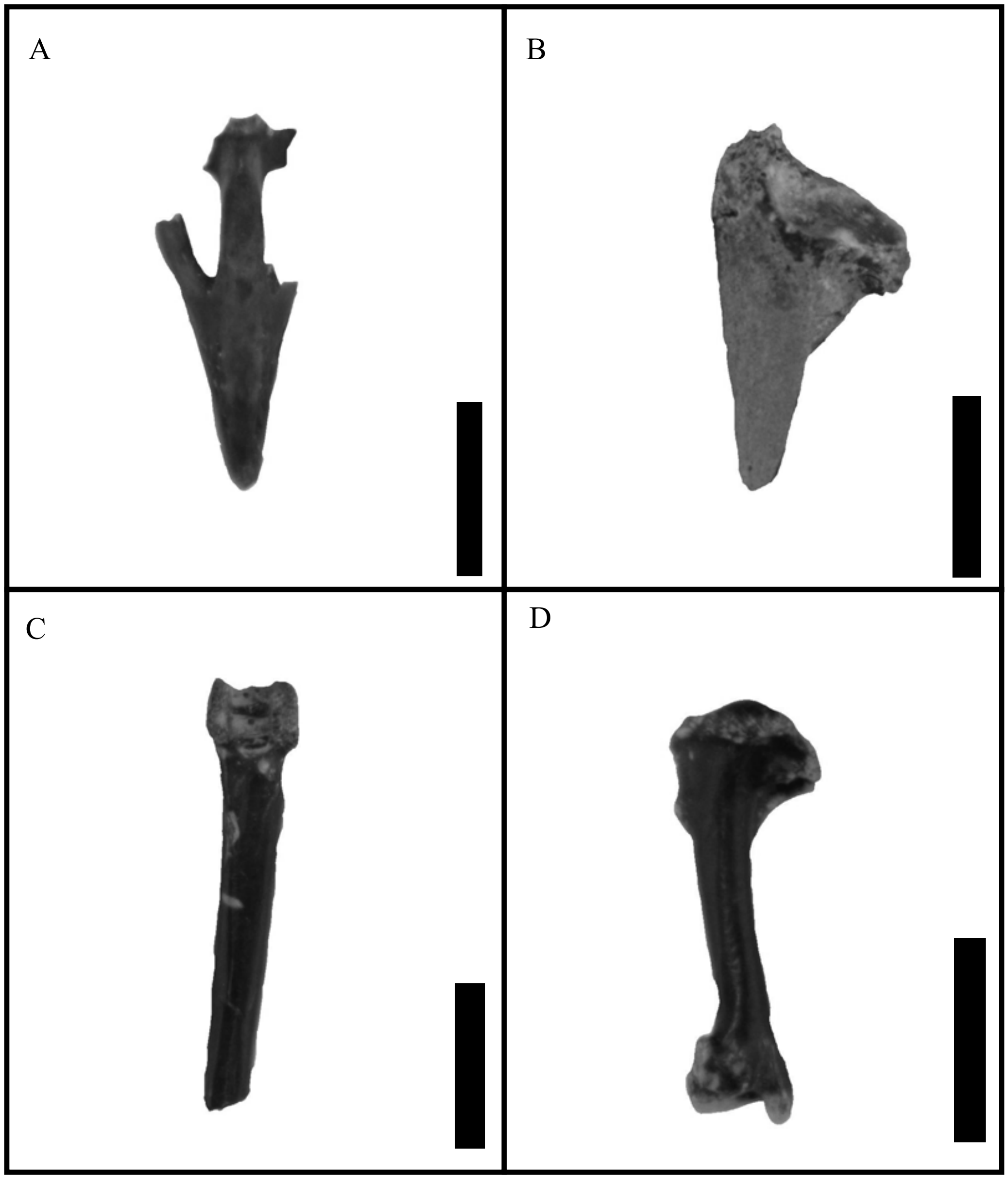

A
B
C
D
E

Plate 2.21: Passeriformes
A: SDSM 28995: *Xanthocephalus xanthocephalus*, Premaxilla, dorsal view.
B: SDSM 30153: *Sturnella neglecta*, Proximal ulna, caudal view.
C: SDSM 30174: ?*Euphagus cyanocephalus*, Distal tibiotarsus, caudal view.
D: SDSM 30132: ?*Vireo* sp., Humerus, cranial view.


A
B
C
D

CHAPTER 3: LITHOSTRATIGRAPHY AND FOSSIL AVIFAUNA OF THE OLIGOCENE ETADUNNA FORMATION

3.1: INTRODUCTION

The Oligocene Etadunna Formation is exposed in the Tirari Desert of South Australia. The stratotype is located at Lake Palankarinna in the Lake Eyre Basin (Stirton et al., 1961). Additional exposures crop out along the more northerly lakes Kanunka, Pitikanta, and Ngapakaldi (Woodburne et al., 1993). Overall, the formation consists of gray to green claystone and dolomitic mudstone with smectite-dolomite-palygorskite mineralogy (Callen and Tedford, 1976). The Etadunna Formation represents a lacustrine deposit with some fluviatile influence (Callen et al., 1986). Support for a lacustrine environment includes lithologic data, such as the dolomitic mudstones, and paleontological data including the presence of foraminifera, freshwater gastropods, ostracodes, dipnoan and teleost fish, crocodiles, turtles, frogs, and aquatic birds (Woodburne et al., 1993). The presence of complete to partially complete fossil skeletons, the fine-grained sediment, and the homogeneity of the claystones support the interpretation of a low-energy lacustrine environment (Woodburne et al., 1993). The late Oligocene age of approximately 24-26 Ma for the Etadunna Formation is based on paleomagnetic and mammalian stage data (Woodburne et al., 1993).

Lake Palankarinna is one of few locations where the Etadunna Formation is exposed, making it a significant fossil locality. Numerous collections have been made, and recent studies document important mammalian faunal turnovers resulting from climatic changes (Case, 2001; Meredith et al., 2008). Preliminary results of the fossil avifauna have been published, but detailed descriptions have not. Early studies noted pelicans, flamingos, ducks, cranes, gulls, rails, songbirds, hawks, shorebirds, and pigeons (Miller, 1963, 1966a, 1966b; Vickers-Rich and van Tets, 1982).

The goals of this part of the study were two-fold: 1) to develop a depositional model for the observed stratigraphic packages (recognized by J.E. Martin) in the Etadunna Formation, and 2) to produce an avifaunal list through the identification of the bird fossils that is stratigraphically tied to these depositional packages. The identification of the numerous bird fossils will add to the known paleofauna of the region, leading to a more complete paleofaunal list from the Etadunna Formation.

3.2: LOCATION OF STUDY AREA

Lake Palankarinna is located in the northern part of South Australia, within the Tirari Desert and the Lake Eyre Basin, 600 km north of Adelaide. The Lake Eyre Basin is divided into two sub-basins, the Tirari Sub-basin in the west, and the Callabonna Sub-basin in the east. Lake Palankarinna lies within the former. The sub-basins are separated by the Birdsville Track Ridge (Callen et al., 1986). Figure 3.1 details the study area. Lake Palankarinna is a relatively small lake, 11 km^2, and lies to the southeast of Lake Eyre. Because the deposits are highly fossiliferous, it has been designated as the Lake Palankarinna Fossil Reserve and has been protected by the South Australian Museum Board from unauthorized fossil collection since 1954 (Alexander and Hibburt, 1996). The stratigraphic units are exposed in low weathered hills that trend north-south on the western side of the lake basin (Figure 3.2). There is a slight dip to the south, so that the older units are exposed in the southern part of the basin and the younger units are exposed in the northern part.

Much of the area surrounding the study location is desert and is covered by sand dunes trending north-south. Two deserts are located east of the Tirari Desert and are separated by the Cooper River, the Sturt Stony Desert to the northeast and the Strzelecki Desert to the southeast. Lake Palankarinna is mostly dry and covered by partly saline or gypsiferous sand (Forbes, 1975). Figure 3.3 details the location of Lake Palankarinna with respect to the surrounding geography.

3.3: GEOLOGIC SETTING

The Lake Eyre Basin lies within the stable craton of Australia where crustal subsidence is low, indicative that tectonic activity has not controlled recent sedimentation (Maroulis et al., 2000). Alley (1998) divided the depositional history of the Lake Eyre Basin into three phases: 1) fluviolacustrine sand, silt, and clay deposition from the latest Paleocene to the middle Eocene; 2) carbonate sand and clay deposition with shallow lakes from the Oligocene to Miocene; 3) deposition of red sand, silt, and clay in fluvial, lacustrine, and eolian settings from the Pliocene to Quaternary.

The Etadunna Formation was deposited after the separation of Australia from Antarctica; this rifting has been linked to the initiation of Antarctic glaciation (~34 Mya) and global cooling during the Eocene-Oligocene transition (Coxall et al., 2005). Some regions, such as the Tibetan Plateau, also experienced aridification during this global cooling (Dupont-Nivet et al., 2007). Documentation of aridification in Australia beginning during this time period and continuing through deposition of the Etadunna

Formation (Janis, 1993) is recognized in floral changes, from rainforest to drier forest types (Megirian et al., 2004), as well as in faunal changes (Vickers-Rich, 1991; Megirian et al., 2004). Mean annual temperatures of 14-20^{o} C and rainfall amounts less than 600 mm during the deposition of the Etadunna Formation have been inferred from paleoclimatic models utilizing sedimentological and fossil vertebrate and invertebrate data (Megirian et al., 2004). As a result of climate change, faunal turnover from archaic to modern species of bandicoot fossils during the late Oligocene was documented from the Etadunna Formation of Lake Palankarinna (Case, 2001; Meredith et al., 2008).

Although the Etadunna Formation is an important fossil locality, the age of the formation has been debated (Woodburne et al., 1993). The Etadunna Formation was originally assigned as ?Oligocene but continued to be problematic (Stirton et al., 1961). The question of age has been described as being the “most difficult problem in the Tirari area” (Stirton et al., 1961, p. 22). The Etadunna Formation has yielded numerous dates, dependent on the method used. The subjacent lithology is also poorly constrained. A stratigraphic comparison of the various age assignments is shown in Figure 3.4 and summarized here. Pollen recovered from boreholes through the Etadunna Formation from Lake Eyre North and Lake Eyre South yielded a middle Miocene age (Johns and Ludbrook, 1963). In the Lake Eyre region, the Etadunna Formation overlies a series of ?Oligocene silts and clays, ?Eocene fine sands, and the ?Cretaceous Winton Formation (Johns and Ludbrook, 1963). Stirton et al. (1968) used the fossil mammalian fauna to infer a late Oligocene to early Miocene age for the Etadunna Formation. They described the Etadunna Formation at Lake Palankarinna overlying the Winton Formation. Overlying the Etadunna Formation is the Pliocene Mampuwordu Sands and/or the

Pliocene Tirari Formation. Norrish and Pickering (1983) used the rubidium/strontium ratio from a sample of illite from the Etadunna Formation to infer an age of 25 Ma. However, the sample location was not tied to the Lake Palankarinna stratigraphy and the under- and overlying strata are not described. Foraminiferal data from a borehole from Lake Palankarinna yielded a late Oligocene age (Lindsay, 1987) without any data on adjacent strata. Fossil mammalian fauna and magnetostratigraphic data yields an age of 24-26 Ma, which is also late Oligocene (Woodburne et al., 1993). The Etadunna is unconformably underlain by the Eocene Eyre Formation and unconformably overlain by either the channel deposits of the Pliocene Mampuwordu Sands or the Pliocene Tirari Formation (Woodburne et al., 1993). The magnetostratigraphic date for the Etadunna Formation has been accepted and used in subsequent publications (e.g. Mackness et al., 2000).

3.4: PREVIOUS WORK

Early expeditions to Lake Palankarinna were conducted to discover localities containing mammalian fossils. This early work was jointly conducted by the South Australian Museum in Adelaide and the University of California Museum of Paleontology. Stirton et al. (1961) described the stratigraphy, as well as the fossils that were found at Lake Palankarinna. As a result of the initial success, fossil expeditions continued (Stirton et al., 1967, 1968). Subsequently, stratigraphic wells were drilled in an attempt to better describe the lithology and to correlate localities (Callen and Plane, 1985).

Fossils from Lake Palankarinna include invertebrates, fish, reptiles, birds, and mammals (Woodburne et al., 1993). The fossils have been collected and placed within five local faunas. A local fauna is a grouping of vertebrate fossils of limited distribution from localities in a close geographic area (Wood et al., 1941). The oldest is the Minkina Local Fauna (LF) and is designated as "A", followed by the Ditjimanka LF (B), the Ngapakaldi LF (C), the Ngama LF (D) and, finally, the Treasure/Lungfish LF (E) (Woodburne et al., 1993).

3.5: LITHOSTRATIGRAPHY

The stratotype of the Etadunna Formation crops out at Lake Palankarinna and was chosen for its completeness (Stirton, 1961). Here, the Etadunna Formation is unconformably overlain by either the Mampuwordu Sands, which represent white, fluvial channel sands, or the Tirari Formation, which is composed of reddish sandstone or green/brown, sandy, gypsiferous claystone. The Etadunna Formation unconformably overlies either the gray, argillaceous sandstones of the Winton Formation (Stirton et al., 1961, 1968; Callen and Plane, 1985), or the Eyre Formation (Woodburne et al., 1993). The overall thickness of the Etadunna Formation, determined through coring, is approximately 30 m and was likely deposited in approximately 2 My (Woodburne et al., 1993).

The lithostratigraphy of the Etadunna Formation at Lake Palankarinna has been published by Stirton et al. (1961) where the formation was divided into nine informal members as follows from oldest to youngest: (1) green argillaceous sandstone; (2) calcareous mudstone and dolomitic limestone; (3) green claystone; (4) green sandstone;

(5) green arenaceous claystone; (6) green argillaceous sandstone; (7) green claystone; (8) calcareous mudstone; and (9) green arenaceous claystone. In this study, I measured and described eight informal members as a result of combining members three and four of Stirton et al. (1961), since they are both green and vary only in grain size.

Stratigraphic sections were trenched, sampled, and described in detail at four localities spanning the western shore of the lake. Smaller sections were trenched between the larger sections, with samples taken from selected units and depicted in Figures 3.5-3.9. See Methods in Chapter 1 for details of sampling and field description details. Results from the grain-size analyses are presented in Appendix 3. The composite stratigraphic section of the eight members defined here is illustrated in Figure 3.10. Figure 3.11 presents an example of a trenched section. The members can be categorized into one of three facies, detailed in Table 3.1, that are repeated in four depositional packages. The following describes the three facies and Figure 3.12 illustrates examples from each:

Siltstone With Root Traces Facies (SRF):

Description: This facies is comprised of an average of 0.70 m of siltstone. The lower contact is gradational and the upper contact is either gradational or scoured. Grain size varies from fine silt to very fine silt and color varies from yellowish gray (5Y 7/2) to light olive gray (10Y 5/4). Analysis of the smear slides reveals an abundance of siliciclastic grains with very few carbonate grains. The facies is massive with root traces occurring locally near the top of the facies. The abundant root traces are light brown (5YR 5/6), branching, and up to 2 cm.

Interpretation: The small grain size indicates a low-energy environment. Root traces signify very low water levels or subaerial exposure. The abundance of siliciclastic grains is a result of the input of sediment from the regional drainage basin. The massive nature of the facies indicates moderate to shallow depth and an oxygenated environment. This facies likely records paludal to shoreline environments in which clastic deposition dominated over carbonate accumulation.

Dolomitic Mudstone Facies (DMF):

Description: This facies averages 0.85 m of very fine-grained dolomitic mudstone. The lower contact is gradational, the upper contact is commonly scoured, and internally the facies is massive. The grain size varies from fine silt to clay. Previous studies (Callen and Plane, 1985) determined that the dominant carbonate mineral is dolomite. Color varies from yellowish gray (5Y 8/1) to very pale orange (10YR 8/2). Analysis of the smear slides reveal very fine grained carbonate grains intermixed with silt to sand size sub-angular to sub-rounded, micritized peloids. Structures are rare, but include conchoidal fractures and local root traces. The root traces branch, are light brown (5YR 5/6), and vary from 0.5 to 1 cm long.

Interpretation: The fine-grained nature of the sediment and the presence of dolomite indicates a low-energy, marginal lacustrine environment. Root traces, however, likely reflect periodic exposure or paludal conditions. The lack of well-developed soil horizons or other indicators of long exposure, coupled with the presence of carbonate grains and peloids, however, indicate deposition predominantly in a shallow, alkaline lacustrine environment.

Brecciated and Fossiliferous Siltstone Facies (BFSF):

Description: This facies averages 1.4 m thick and is composed mainly of siltstone. The lower contact is typically scoured and the upper contact is gradational. Overall, the facies is gradational from a basal intraformational breccia with a silty matrix upward into a massive siltstone. The base of this facies is an intraformational breccia that consists of dusky yellow (5Y 6/4) medium-grained siltstone with numerous angular clasts that become more rounded upward through the facies. The clasts measure 1-2 cm and are composed of the underlying yellowish gray (5Y 7/2) mudstone (Figure 3.12 C). The grain size within the upper silty part of the facies increases toward the top. The upper part of this facies consists of light olive gray (5Y 5/2) medium-grained siltstone that is massive and fossiliferous. The fossiliferous units can be correlated to known fossil localities described in Woodburne et al. (1993) based on lithologic and locality data. Analysis of the smear slides indicate both carbonate and siliciclastic grains; peloids are more common near the base of the facies, whereas the upper part of the facies consists of predominantly of siliciclastic sediment.

Interpretation: The basal scours and rip-up clasts from the underlying facies record high-energy processes that may reflect initial flood or sheet flood deposits. The carbonate peloids present in the lower part of the facies are consistent with lacustrine deposition. Water depth is difficult to constrain, and may have been variable during deposition, but was likely moderate during deposition of the more massive portion of the facies, which is consistent with an oxygenated water-bottom experiencing thorough bioturbation. The upper part of the facies also becomes more siliciclastic, possibly reflecting wetter conditions during which clastic sediment was delivered to the lake from the drainage basin. The fossil fish recovered from this facies lends additional support to the interpretation of subaqueous deposition in an offshore environment.

Facies Association

The stratigraphy of the Etadunna Formation at Lake Palankarinna can be divided into four depositional packages. Although most of the facies are silty, variations in grain size, sedimentary structures, and fossils allow for interpretation of the vertical trends in the stratigraphy. The following is a summary of the depositional packages defined within the Etadunna Formation in stratigraphic order.

Package 1: Siltstone with Roots Facies-Dolomitic Mudstone Facies

The basal package represents a shallowing phase of the lake system. This package grades upward from fine siltstone to dolomitic mudstone which I interpret as a change from more open to more marginal lacustrine conditions with periodic, minor subaerial exposure as suggested by the abundant root traces.

Package 2: Brecciated and Fossiliferous Siltstone Facies-Siltstone with Root Traces Facies

The second package records an initial deepening phase that yields to a shallowing phase. The base of the package contains rip-up clasts and an abundance of siliciclastic grains. Near the top of the BFSF water levels deepened, as fossil fish are present. The package then grades upward into SRF indicating a gradual shallowing with minor subaerial exposure, represented by the root traces.

Package 3: Brecciated and Fossiliferous Siltstone Facies-Dolomitic Mudstone Facies

The base of the third package reflects another deepening phase of the lake, as suggested by the basal scours and rip-up clasts, and gradation into a siltstone with fossil fish. The BFSF is overlain by the DMF, indicating shallower, alkaline conditions, as inferred by the presence of carbonate.

Package 4: Brecciated and Fossiliferous Siltstone Facies

The uppermost package consists of only the BFSF and indicates another abrupt increase in water depth, evidenced by the rip-up clasts at the base and the presence of fish fossils. Both the SRF and the DMF are not present above the BFSF. However, the package is likely truncated because the Etadunna Formation is unconformably overlain by the Mampuwordu Sands or the Tirari Formation (Fig. 3.5).

Facies Summary

The packages found within the Etadunna Formation represent changes in water levels and are reflected in the facies stacking pattern. Each package represents a rapid in-filling followed by a gradual shallowing of the lake. However, a complete, symmetrical deepening-shallowing cycle is not recorded within the study sites, likely as a result of the rapid changes in water levels and consequent truncated facies transitions.

The facies association of BFSF-SRF-DMF is the inferred facies succession for a complete cycle (Figure 3.13). Package 1 probably represents the upper part of this idealized cycle. Package 2 displays an abrupt increase in lake level followed by a gradual shallowing, likely with periodic subaerial exposure, but the package does not contain the DMF, indicating that an alkaline, shallow-water lake did not form prior to the subsequent deepening episode. The third package also records an initial, abrupt increase in water level of the BFSF but is stratigraphically followed by the DMF, without the intervening SRF, indicating a rapid change to alkaline, shallow-water deposition. The upper package represents only the first half of the idealized cycle, with a rapid increase in water level.

Table 3.2 summarizes the stratigraphy, detailing the relationship between the stratigraphic position of each member, each facies, and local fauna.

3.6: FOSSIL AVIFAUNA

Fossil birds are among the fossil remains found in the Etadunna Formation of Lake Palankarinna, and are relatively common. Most of the collected fossils have some stratigraphic control, allowing them to be put into the appropriate local faunas but not with resolution precise enough to assign to facies or packages as employed in my investigation. Vickers-Rich (1991) summarized the families of fossil birds that have been recovered from Lake Palankarinna. However, most bird families have not been studied in depth. Much of the total collection of avian fossils from the Etadunna Formation is divided among many researchers. Table 3.3 compares the list from Vickers-Rich et al. (1991) and the fossils identified here.

Some of the previously collected and identified fossil avifauna from the South Australia Museum collection is included in this study. These fossils are included in Appendix 4 and are designated with specimen numbers bearing the prefix “P”. Unfortunately, most of the Anseriformes are not included, as these specimens were currently the focus of a researcher at the SAM and were unavailable for this study. Therefore, a complete avifauna list from this formation cannot be included here.

Systematic Paleontology

The following list of specimens was identified from the University of California Museum of Paleontology collection loaned to the author. Taxonomic data are organized in stratigraphic order by locality and included in Appendix 4, along with size measurements. Uncertainty of identification is indicated by "?".

Class AVES Linnaeus, 1759

Order GALLIFORMES Temminck, 1820

Family PHASIANIDAE Vigors, 1825

Plate 1 A

Ecology: Pheasants and grouse are well adapted for terrestrial life and are mostly nonmigratory. Although most are herbivorous, some eat small invertebrates (Sibley et al., 2001).

Referred Specimens:

Humerus: JEH006

Femur: 22958

Tarsometatarsus: 21914

Description: The condyles of the humerus have been sheared off. Diagnosis is based on overall size and shape of the bone. The lateral condyle of the femur is rounded. Tarsometatarsus trochlea III extends past trochleae II and IV.

Occurrence: BFSF-SRF of Package 2.

Order ANSERIFORMES Wagler, 1831

Family ANATIDAE Vigors, 1825

Plate 1 B-D

Ecology: The ducks and geese are mostly herbivorous, migratory water birds that inhabit a wide variety of aquatic habitats, where they breed (Sibley et al., 2001).

Referred Specimens:

Coracoid: JEH007A; SAR302A

Scapula: JEH007B

Femur: 22712

Tibiotarsus: 16082

Description: JEH007A has a large facet for articulation with the humerus. The sternal facet of the distal coracoid is curved and well developed. Ridges are present on bone surface. The scapula also has a large humeral (glenoid) facet, as well as a projection of the acromion. The femur has a well developed groove on the fibular trochlea. An intermuscular ridge is present on the distal part of the shaft. The internal condyle is somewhat flattened. The supratendinal bridge of the tibiotarsus is triangular. The condyles are rounded and splay.

Occurrence: SRF of Package 2 and BFSF of Package 3; BFSF of Package 4.

Order PROCELLARIIFORMES Fürbringer, 1888

Family DIOMEDEIDAE Gray, 1840

?*Diomedea* sp. Linnaeus, 1758

Plate 2 A

Ecology: This family consists of carnivorous seabirds that feed mostly on squid and fish. They are migratory (Sibley et al., 2001).

Referred Specimen:

Tibiotarsus: YBQ02-09

Description: The condyles are incomplete, but the overall shape of the fossil is similar to *Diomedea* and is larger than *Palaelodus*.

Occurrence: BFSF-SRF of Package 2.

Order PELECANIFORMES Sharpe, 1891

Family PHALACROCORACIDAE Bonaparte, 1854

Ecology: The cormorants are medium to large water birds with long body and neck, and a strong hooked beak. They can be found worldwide, with greatest diversity in tropical and temperate zones (del Hoya et al., 1992). Cormorants are well adapted to aquatic environments and prefer stretches of open water, either freshwater or marine (Sibley et al., 2001). Their skeletons are not as pneumatized as other birds, allowing for easier diving (del Hoya et al., 1992).

Phalacrocorax sp. Brisson, 1760

Plate 2 B

Referred Specimen:

<u>Scapula</u>: JEH005

Description: The humeral (glenoid) facet is large, and the acromion has a very pronounced curve.

Occurrence: BFSF-SRF of Package 2.

Order CICONIIFORMES Garrod, 1874

Family PALAELODIDAE Stejneger, 1885

Ecology: Palaelodids are a group of extinct birds, whose habitats can be inferred from skeletal shape and comparison to related taxon. These birds were swimmers and may have developed a filter-feeding system (Feduccia, 1999).

Palaelodus sp. Milne-Edwards, 1863

Plate 2 C; Plate 3 A-B

Referred Specimens:

Ulna: JEH011A

Carpometacarpus: JEH011B

Tibiotarsus: JEH009A; 21890; 22932; 22037

Tarsometatarsus: JEH011C; 22046; VP0360

Description: The dorsal condyle of the ulna is well rounded. The carpometacarpus is missing the minor metacarpal and the articulation facet is rounded with a groove at the base. The distal end of the tibiotarsus of *Palaelodus* is highly diagnostic in the shape and position of the supratendinal bridge as seen in JEH009, 21890, and 22037. The articular end is missing in 22932, but the beginning of the supratendinal bridge is present. Trochlea III of the tarsometatarsi is the longest and has a prominent groove. Trochlea II is the shortest and is retracted toward the shaft. The distal foramen penetrates both the dorsal and plantar sides. JEH011C is broken into three pieces; the proximal end and the shaft can be articulated, but not with the distal end. The tarsometatarsus of VP0360 is that of a juvenile and the trochleae are missing. However, the shape of the bone seems to follow that of *Palaelodus* in the groove trending toward the distal foramen.

Occurrence: BFSF and SRF of Package 2; SRF of Package 2 and BFSF of Package 3; DMF of Package 3; BFSF of Package 4.

Family PHOENICOPTERIDAE Bonaparte, 1838

Ecology: Flamingos are tall, omnivorous waders that eat algae and small invertebrates. Nests are typically built on mudflats. These birds are migratory (Sibley et al., 2001).

Phoenicopterus sp. Linnaeus, 1758

Plate 3 C; Plate 4 A

Referred Specimens:

Ulna: 22306

Carpometacarpus: JEH010C

Tarsometatarsus: YBQ02-07

Description: The dorsal condyle of the ulna is rounded and makes an approximately 90^{o} angle with the shaft. The ventral condyle of the ulna is reduced. The projections of the pisiform process and extensor process of the carpometacarpus are prominent, and the anterior carpal fossa is well developed. The shaft of YBQ02-07 contains a groove on the dorsal and plantar sides.

Occurrence: BFSF and SRF of Package 2; SRF of Package 2 and BFSF of Package 3; DMF of Package 3; BFSF of Package 4.

Family THRESKIORNITHIDAE Richmond, 1917

Ecology: Ibises are large wading birds that inhabit a variety of wetlands and freshwater marshes, where they feed on aquatic prey (Sibley et al., 2001).

?*Eudocimus* sp. Wagler, 1832

Plate 4 B

Referred Specimen:

Tibiotarsus: 21893

Description: The curvature of the condyles match that of *Eudocimus*, but the fossil specimen is smaller.

Occurrence: BFSF of Package 4.

Order GRUIFORMES Bonaparte, 1854

Family ?GRUIDAE Vigors, 1825

Plate 4 C

Ecology: Cranes inhabit open habitats of freshwater wetlands to uplands. They are migratory and are opportunistic feeders (Sibley et al., 2001).

Referred Specimen:

Tarsometatarsus: VP0703

Description: The intercotylar eminence is elevated and the hypotarsus is prominent and rounded.

Occurrence: BFSF and SRF of Package 2.

Order RALLIFORMES Reichenbach, 1854

Family RALLIDAE Reichenbach, 1854

Plate 4 D

Ecology: Rails and coots live mostly in marshlands, with some species preferring more terrestrial environments, although most nest near water. They are opportunistic feeders and migratory (Sibley et al., 2001).

Referred Specimen:

Humerus: 22714; 22711

Description: The dorsal condyle is rounded and curves toward and over the ventral condyle. The internal epicondyle projects down. On 22711 the dorsal condyle is worn but curves toward the ventral condyle. There is a large attachment for the brachialis muscle.

Occurrence: BFSF and SRF of Package 2; SRF of Package 2 and BFSF of Package 3; DMF of Package 3.

Order CHARADRIIFORMES Fürbringer, 1888

Plate 5 A

Ecology: This group includes the shorebirds that often feed on invertebrates and fish from shallow water. Most are migratory (Sibley et al., 2001).

Referred Specimen:

Carpometacarpus: JEH007C

Description: The pisiform process is small and does not project outward very much. The extensor process is rounded.

Occurrence: BFSF and SRF of Package 2; SRF of Package 2 and BFSF of Package 3; DMF of Package 3.

Family RECURVIROSTRIDAE Bonaparte, 1831

Plate 5 B-C

Ecology: Stilts and avocets feed on small invertebrates from shallow water. They nest near water and often move with habitat availability (Sibley et al., 2001).

Recurvirostra sp. Linnaeus, 1758

Referred Specimen:

Tarsometatarsus: JEH009B

Description: Trochlea III is slightly longer than II or IV. Trochlea II is missing, but seems to be retracted.

Occurrence: BFSF and SRF of Package 2.

Order FALCONIFORMES Seebohm, 1890

Family ACCIPITRIDAE Vieillot, 1816

Plate 6 A-B

Ecology: Hawks, eagles, and kites are migratory predators (raptors) that utilize most terrestrial habitats, feeding on mammals, birds, fish, and reptiles. Hawks build their nests in trees (Sibley et al., 2001).

Referred Specimens:

Radius: 22713

Ungual: VP0365

Description: The scapho-lunar facet is similar to that of *Pandion haliaetus*, but the fossil is a little smaller than Recent specimens. The ungual is large and possibly attributed to *Aquila audax*, although a comparison specimen was not available.

Occurrence: SRF of Package 2 and BFSF of Package 3.

Order PSITTACIFORMES Wagler, 1830

Family CACATUIDAE Gray, 1840

Plate 6 C

Ecology: This family consists of arboreal birds that feed on fruit and seeds. Most are nonmigratory and nest in tree cavities (Sibley et al., 2001).

Cacatua sp. Vieillot, 1817

Referred Specimen:

Coracoid: 16095B

Description: Deep scapular cotyla with a prominent ridge behind it. The furcular facet is rounded.

Occurrence: SRF of Package 2 and BFSF of Package 3.

Order PASSERIFORMES Linnaeus, 1758

Family CORVIDAE Vigors, 1825

Plate 6 D

Ecology: Ecology: Crows, ravens, and jays are a group of perching birds that utilize most terrestrial habitats. They are omnivorous, nest in trees, and are non-migratory to partially migratory (Sibley et al., 2001).

Referred Specimen:

Tarsometatarsus: JEH007

Description: All trochleae are even and square with a prominent groove on the central trochlea.

Occurrence: SRF of Package 2 and BFSF of Package 3.

Habitat Divisions

The fossil bird families from the Etadunna Formation that are described above and included in the SAM collection are divided here into three groupings based on their habitat preferences; diving birds, shallow-water birds, and terrestrial birds. Bird taxa not described above are part of the SAM collection. These groupings allow for comparisons of fossil avian diversity through the formation.

The first category includes the Phalacrocoracidae, which are classified as diving birds. This family is highly specialized for underwater feeding by diving (Sibley et al., 2001). Therefore, where present the water depth is inferred to be at least of moderate depth.

Shallow-water birds is the second category and includes the families Anatidae, Procellariide, Palaelodidae, Phoenicopteridae, Ciconiidae, Threskiornithidae, Gruidae, Rallidae, an unidentified genus of Charadriiformes, and Recurvirostridae. Although ducks and geese are water birds, the required depth is shallower than the families in the previous group. The families of the shallow-water birds are found near water, where they feed by wading. Most of this group nest near water and are migratory (Sibley et al., 2001). The presence of at least shallow water is inferred from the presence of birds of this group.

The final category is the terrestrial birds, including Casuariidae, Phasianidae, Accipitridae, Cacatuidae, and Corvidae. The group exploits a variety of habitats, not closely linked with water and generally is associated with wooded areas (Sibley et al., 2001). Terrestrial birds represent the outer fringe of the lake system.

Discussion of Fossil Avifauna

The fossils from the Etadunna Formation exhibit moderate preservation. Few skeletons are recovered and many of the bones are broken or worn. However, fossil eggshells have also been recovered from the formation. It is inferred from the presence of eggshells and the nature of preservation that energy levels were moderate. The abundance of shallow-water birds and scarcity of terrestrial birds is likely an artifact of the lack of true terrestrial deposits.

Stratigraphic data combined with fossil data of an area allows for an analysis of diversity through geologic time, and both are available for the Etadunna Formation. Fossil avifauna from the University of California Museum of Paleontology and the South Australian Museum have been separated into five local faunas described by Woodburne et al. (1993; Table 3.2) and are described below. Table 3.4 summarizes the occurrences and abundances of each family.

Minkina Local Fauna A:

Local Fauna A is the oldest of the formation and spans one lithostratigraphic package of the Brecciated and Fossiliferous Siltstone Facies (BFSF) and the Siltstone with Root Traces Facies (SRF). The Palaelodidae and Phoenicopteridae are the most common of the bird families, with 15 and 13 fossil specimens, respectively. Phasianidae is the next most abundant, represented by only three specimens. The Procellariidae, Phalacrocoracidae, Gruidae, Rallidae, Recurvirostridae, and ?Charadriiformes are each represented by a single specimen.

Ditjimanka Local Fauna B and Ngapakaldi Local Fauna C:

At Lake Palankarinna, local faunas B and C are combined (Woodburne et al, 1993). They span the SRF of the top of Package 2 and the BFSF at the bottom of Package 3. Anatidae, Phoenicopteridae, Accipitridae are each represented by three specimens. Palaelodidae are represented by two specimens. Rallidae, a genus of Charadriiformes, Cacatuidae, and Corvidae are each represented by one specimen.

Ngama Local Fauna D:

The Ngama Local Fauna is found within the Dolomitic Mudstone Facies (DMF), which forms the top of Package 3. The most abundant family from this local fauna is the Phoenicopteridae with 11 specimens, followed by the Palaelodidae with five. The Casuariidae are represented by two specimens, with Ciconiidae, Rallidae, and Charadriiformes each represented by a single specimen.

Treasure/Lungfish Local Fauna E:

This local fauna is the uppermost of the Etadunna Formation and is found within the BFSF of Package 4. Most of the avifauna are from three families from the order

Ciconiiformes, including two specimens from both the Palaelodidae and Phoenicopteridae, and one from Threskiornithidae. There is also one specimen from the Anatidae.

The fossil data in stratigraphic context are summarized in Figure 3.14. Shallow-water birds are the most abundant eco-group of each facies. Only one specimen belonging to the diving birds eco-group was recovered, suggesting overall shallow-water depths during lacustrine deposition. The diving bird was recovered from the BFSF, the deepest inferred facies, of Package 2. During deposition of the DMF of Package 3, when the lake water would be shallow and more alkaline, the Ciconiiformes dominate the fauna, with 17 of 21 specimens belonging to this order. Although the habits of the palaelodids can only be inferred, the flamingos and storks often feed in shallow, often alkaline waters where food is concentrated (Sibley et al., 2001). Although most of the fossil birds from the Etadunna Formation are migratory, it is unlikely that the collections from individual facies represent migration events. The formation was deposited over 2 My (Woodburne et al., 1993) and the facies are time-averaged.

3.7: CONCLUSIONS

The lithostratigraphy of the Etadunna Formation is divided into three facies that are repeated in four stratigraphic packages. The packages represent wetting and drying cycles of the lake and were deposited in marginal to offshore lacustrine and paludal environments. Fossil fish are indicative of relatively deep water-levels during offshore deposition of the BFSF, while root traces and dolomitic mudstone imply shallow-water deposition in a paludal setting and periodic exposure. It is interpreted that the Etadunna

Formation was deposited in a basin that was rapidly in-filled by flood deposits (BFSF) that was followed by deposition during a prolonged drying phase (SRF-DMF).

The inclusion of stratigraphic data with the fossil avifauna can be used to corroborate depositional environments determined by facies analysis. The avifauna from this study is dominated by specimens from Palaeolodidae and Phoenocopteridae, although this is likely an artifact of the lack of the majority of the Anseriformes data. Nevertheless, the abundance of Ciconiiformes, especially during deposition of the DMF, where the group represents 80% of the fauna, corroborates the facies interpretation of water depth, as these birds feed in shallow-water environments.

The fossils of the Etadunna Formation are collected by local fauna rather than facies. This method collects across facies and package boundaries limiting the inferences that can be made from changes in depositional environments. The fossils would be more useful to interpret temporal changes if collected from each facies rather than local faunas.

Table 3.1: Etadunna Formation facies table.

Table 3.1: Descriptions of Etadunna Formation Facies

Facies	Average Thickness	Average Grain Size	Structures	Color	Bedding	Depositional Environment
Brecciated and Fossiliferous Siltstone Facies (BFSF)	1.4 m	10.9 µm	Intraformational breccia; fish fossils	Dusky yellow (5Y 6/4); upper part of this facies is light olive gray (5Y 5/2)	Massive	Marginal to offshore lacustrine
Siltstone With Root Traces Facies (SRF)	0.70m	9.3 µm	Root traces	Varies from light olive gray (10Y 5/4) to yellowish gray (5Y 7/2)	Massive to thinly bedded	Marginal lacustrine with some subaerial exposure
Dolomitic Mudstone Facies (DMF)	0.85 m	5.4 µm	Conchoidal fractures; root traces	Varies from yellowish gray (5Y 8/1) to very pale orange (10YR 8/2)	Massive to thinly bedded	Paludal

Table 3.2: Stratigraphic position of members, facies, and local faunas of the Etadunna Formation, Lake Palankarinna.

Table 3.2: Stratigraphic position of members, facies, and local faunas of the Etadunna Formation, Lake Palankarinna. The member number corresponds to divisions herein. Member numbers in parentheses correspond to divisions in Stirton et al. (1961). Facies are described herein. Local faunas as described in Woodburne et al. (1993).

Member (Stirton et al., 1946)	**Facies**	**Local Fauna (LF)**
8 (9)	Brecciated and Fossiliferous Siltstone Facies	E: “Treasure/Lungfish” LF
7 (8)	Dolomitic Mudstone Facies	D: Ngama LF
6 (7)	Brecciated and Fossiliferous Siltstone Facies	B,C: Ditjimanka LF, Ngapakaldi LF
5 (6)	Siltstone with Root Traces Facies	B,C: Ditjimanka LF, Ngapakaldi LF
4 (5)	Siltstone with Root Traces Facies	A: Minkina LF
3 (3/4)	Brecciated and Fossiliferous Siltstone Facies	A: Minkina LF
2 (2)	Dolomitic Mudstone Facies	
1 (1)	Siltstone with Root Traces Facies	

Table 3.3: Comparison of bird taxa from Vickers-Rich et al. (1991), and this study.

Table 3.3: Comparison of bird taxon from Vickers-Rich et al. (1991), and this study.

Order	**Family**	**Vickers-Rich et al. (1991)**	**This study**
Galliformes	Phasianidae		X
Anseriformes	Anatidae	X	X
Procellariformes	Diomedeidae		X
Pelecaniformes	Phalacrocoracidae		X
	Pelecanidae	X	
Ciconiiformes	Palaelodidae	X	X
	Phoenicopteridae	X	X
	Threskiornithidae		X
Gruiformes	Gruidae	X	X
Ralliformes	Rallidae	X	X
Charadriiformes		X	
	Recurvirostridae		X
Burhinidae		X	
Falconiformes	Accipitridae	X	X
Psittaciformes	Cacatuidae		X
Passeriformes		X	
	Columbidae	X	X

Table 3.4: Occurrences and abundances of bird families within local faunas.

Table 3.4: Occurrences and abundances of the fossil avifauna of the Etadunna Formation. Numbers indicate the number of specimens for each family. Specimens included here and from the SAM.

	Order	Casuariiformes	Galliformes	Anseriformes	Procellariiformes	Pelecaniformes	Ciconiiformes			
LF	**Family**	Casuariidae	Phasianidae	Anatidae	Procellariidae	Phalacrocoracidae	Palaelodidae	Phoenicopteridae	Ciconiidae	Threskiornithidae
A		0	3	0	1	1	15	13	0	0
B/C		0	0	3	0	0	2	3	0	0
D		2	0	0	0	0	5	11	1	0
E		0	0	1	0	0	2	2	0	1
Total		2	3	4	1	1	24	29	1	1

	Order	Gruiformes	Ralliformes	Charadriiformes		Falconiformes	Psittaciformes	Passeriformes	
LF	**Family**	?Gruidae	Rallidae	?	Recurvirostridae	Accipitridae	Cacatuidae	Corvidae	n=
A		1	1	1	1	0	0	0	37
B/C		0	1	1	0	3	1	1	15
D		0	1	1	0	0	0	0	21
E		0	0	0	0	0	0	0	6
Total		1	3	3	1	3	1	1	79

Figure 3.1: Map of South Australia indicating the general location of Lake Palankarinna

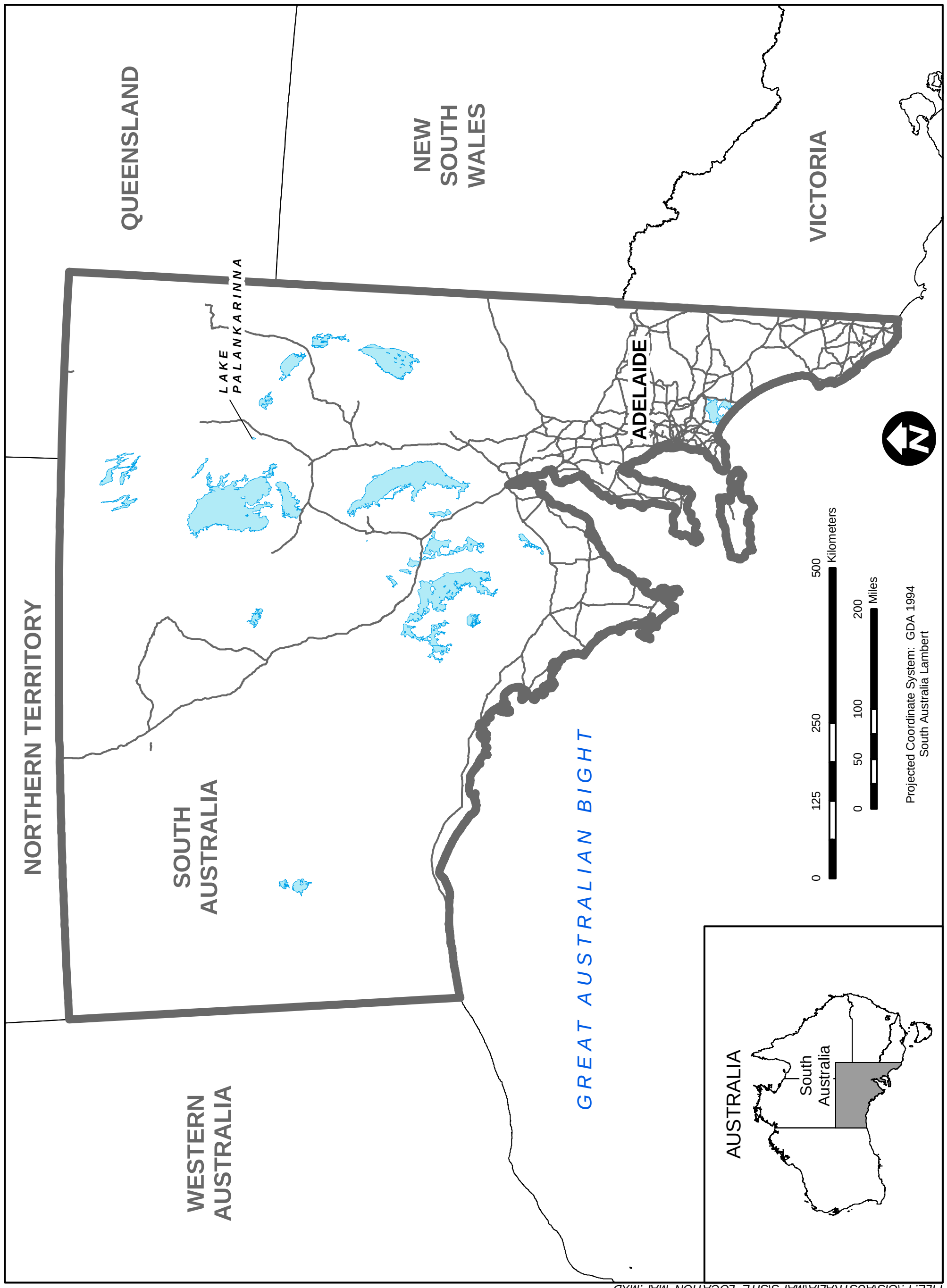

QUEENSLAND
NEW SOUTH WALES
VICTORIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
WESTERN AUSTRALIA
LAKE PALANKARINNA
ADELAIDE
GREAT AUSTRALIAN BIGHT
0 125 250 500 Kilometers
0 50 100 200 Miles
Projected Coordinate System: GDA 1994
South Australia Lambert
AUSTRALIA
South Australia
FILE: F:\GIS\AUSTRALIA\MAPS\SITE_LOCATION_MAP.MXD

Figure 3.2: View looking north at Lake Palankarinna. Exposure of the Etadunna Formation on the western side of the lake basin. Lower green beds are the Etadunna Formation and the upper red beds are the Tirari Formation.

Figure 3.3: Map of the Lake Eyre Basin including Lake Palankarinna and the regional geography referred to in text. The dashed gray line indicates the extent of the Lake Eyre Basin. Lake Palankarinna is situated in the Tirari Desert, south of Cooper Creek.

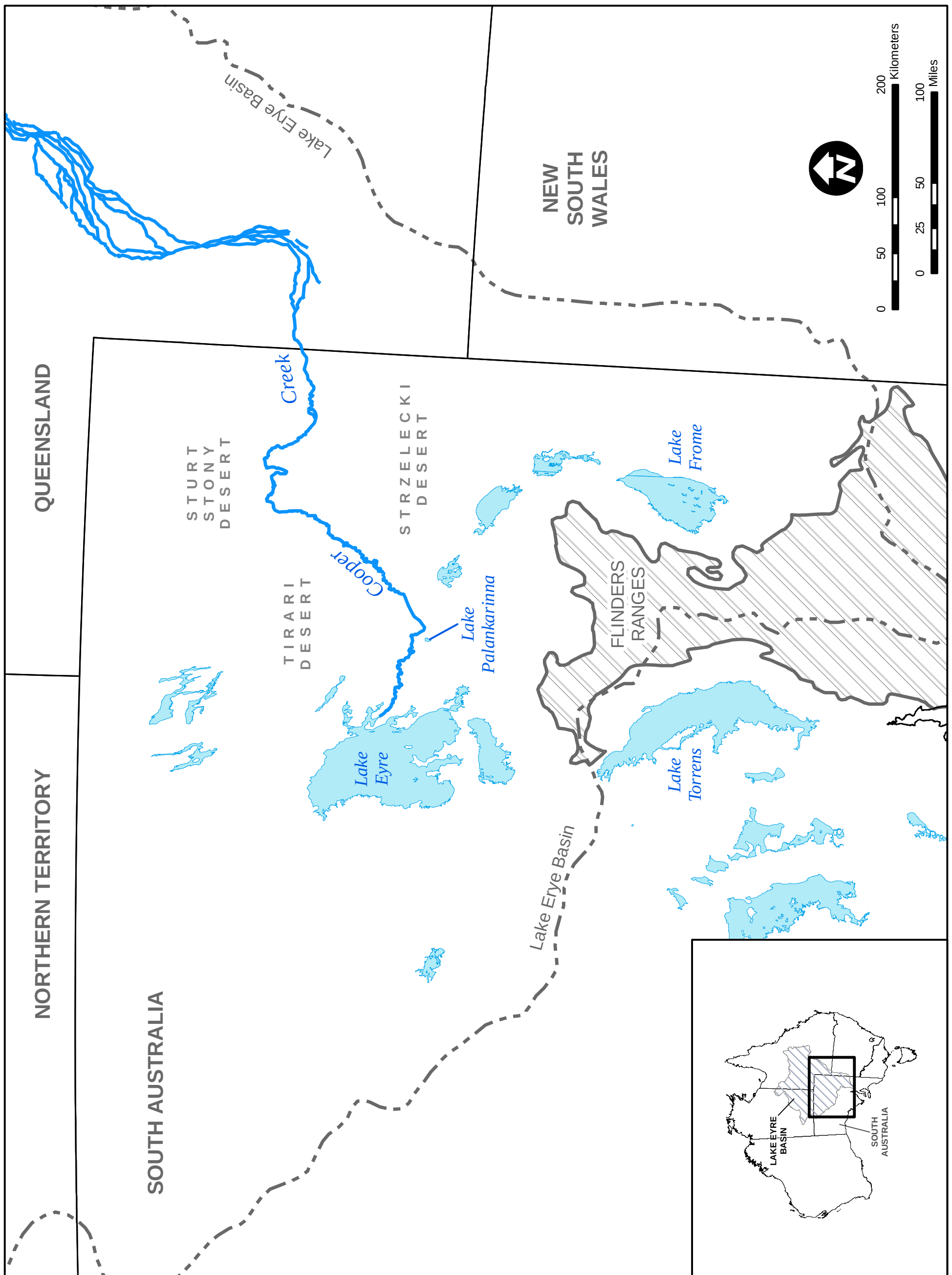

QUEENSLAND
NORTHERN TERRITORY
SOUTH AUSTRALIA
NEW SOUTH WALES
Lake Eyre Basin
Lake Erye Basin
STURT STONY DESERT
STRZELECKI DESERT
TIRARI DESERT
Cooper Creek
Lake Palankarinna
Lake Eyre
Lake Frome
Lake Torrens
FLINDERS RANGES
N
0 50 100 200 Kilometers
0 25 50 100 Miles
LAKE EYRE BASIN
SOUTH AUSTRALIA
FILE: F:\GIS\AUSTRALIA\MAPS\RegionalSystems_LOCATION_MAP.MXD

Figure 3.4: Variations in age assignments and stratigraphic nomenclature of the Cenozoic units within the Lake Eyre Basin. Numbers to the right of the epoch indicate millions of years ago.

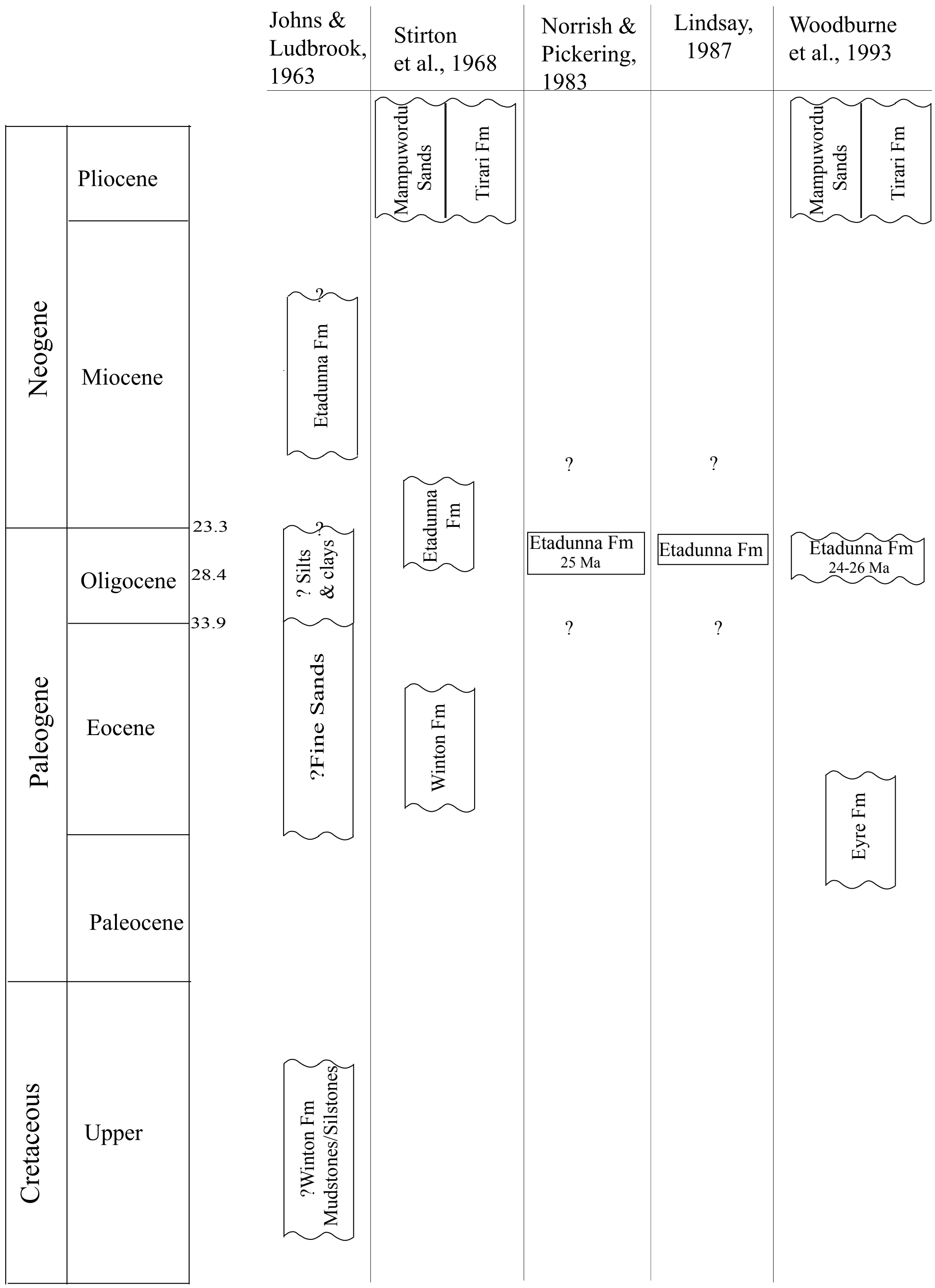
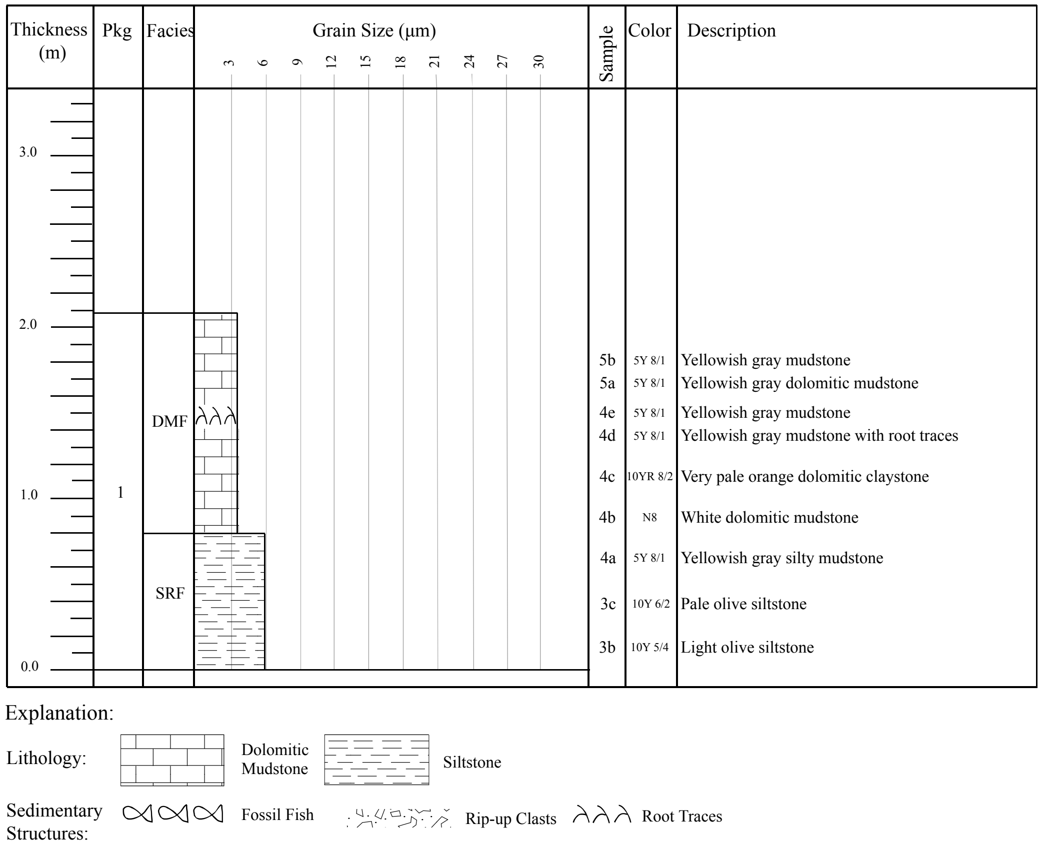

Johns & Ludbrook, 1963
Stirton et al., 1968
Norrish & Pickering, 1983
Lindsay, 1987
Woodburne et al., 1993
Neogene
Paleogene
Cretaceous
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper
23.3
28.4
33.9
Mampuwordu Sands
Tirari Fm
Etadunna Fm
? Silts & clays
?Fine Sands
?Winton Fm Mudstones/Silstones
Winton Fm
Etadunna Fm 25 Ma
Etadunna Fm 24-26 Ma
Eyre Fm

Figure 3.5: Stratigraphic column from SSB section the Etadunna Formation.

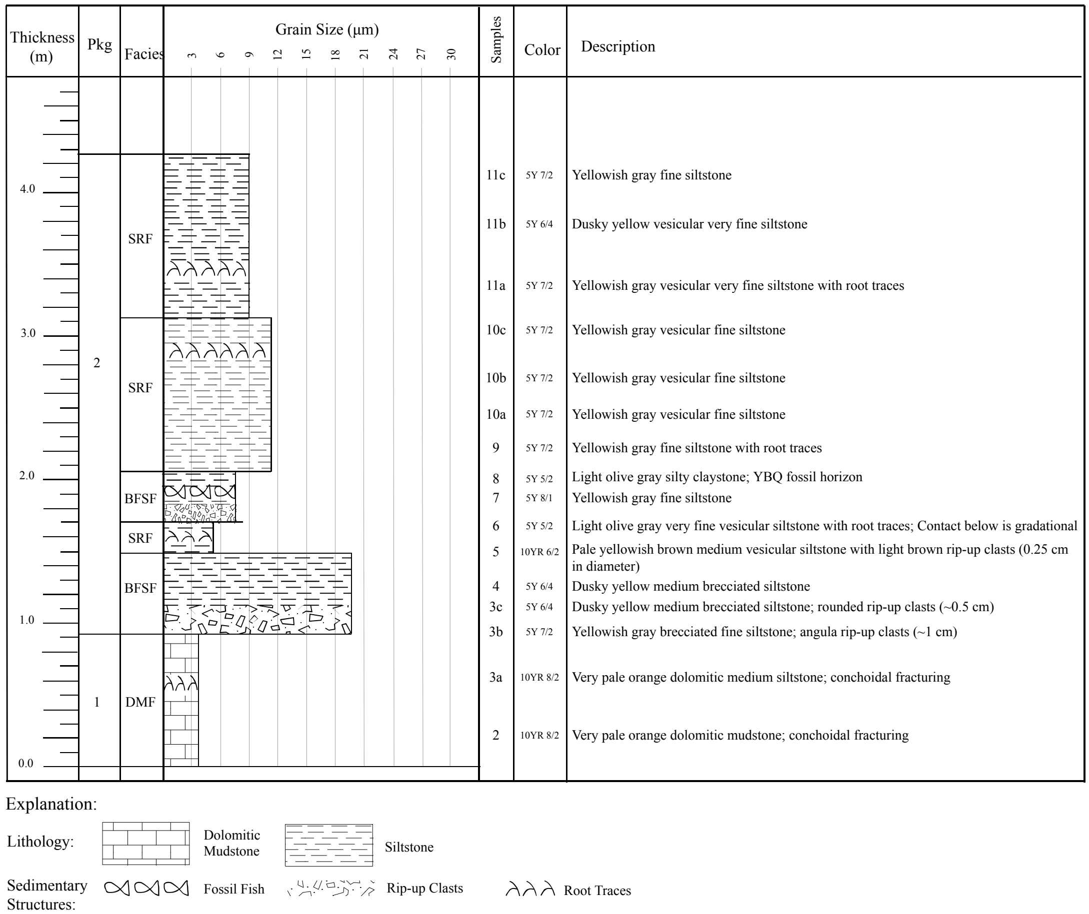
SSB Section



Thickness (m)
Pkg
Facies
Grain Size (μm)
3
6
9
12
15
18
21
24
27
30
Sample
Color
Description
3.0
2.0
1.0
0.0
1
DMF
SRF
5b
5Y 8/1
Yellowish gray mudstone
5a
5Y 8/1
Yellowish gray dolomitic mudstone
4e
5Y 8/1
Yellowish gray mudstone
4d
5Y 8/1
Yellowish gray mudstone with root traces
4c
10YR 8/2
Very pale orange dolomitic claystone
4b
N8
White dolomitic mudstone
4a
5Y 8/1
Yellowish gray silty mudstone
3c
10Y 6/2
Pale olive siltstone
3b
10Y 5/4
Light olive siltstone
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossil Fish
Rip-up Clasts
Root Traces

Figure 3.6: Stratigraphic column from SYB section the Etadunna Formation.

SYB Section



Thickness (m)
Pkg
Facies
Grain Size (μm)
3 6 9 12 15 18 21 24 27 30
Samples
Color
Description
4.0
3.0
2.0
1.0
0.0
2
1
SRF
SRF
BFSF
SRF
BFSF
DMF
11c 5Y 7/2 Yellowish gray fine siltstone
11b 5Y 6/4 Dusky yellow vesicular very fine siltstone
11a 5Y 7/2 Yellowish gray vesicular very fine siltstone with root traces
10c 5Y 7/2 Yellowish gray vesicular fine siltstone
10b 5Y 7/2 Yellowish gray vesicular fine siltstone
10a 5Y 7/2 Yellowish gray vesicular fine siltstone
9 5Y 7/2 Yellowish gray fine siltstone with root traces
8 5Y 5/2 Light olive gray silty claystone; YBQ fossil horizon
7 5Y 8/1 Yellowish gray fine siltstone
6 5Y 5/2 Light olive gray very fine vesicular siltstone with root traces; Contact below is gradational
5 10YR 6/2 Pale yellowish brown medium vesicular siltstone with light brown rip-up clasts (0.25 cm in diameter)
4 5Y 6/4 Dusky yellow medium brecciated siltstone
3c 5Y 6/4 Dusky yellow medium brecciated siltstone; rounded rip-up clasts (~0.5 cm)
3b 5Y 7/2 Yellowish gray brecciated fine siltstone; angula rip-up clasts (~1 cm)
3a 10YR 8/2 Very pale orange dolomitic medium siltstone; conchoidal fracturing
2 10YR 8/2 Very pale orange dolomitic mudstone; conchoidal fracturing
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossil Fish
Rip-up Clasts
Root Traces

Figure 3.7: Stratigraphic column from SCQ section the Etadunna Formation.

SCQ Section

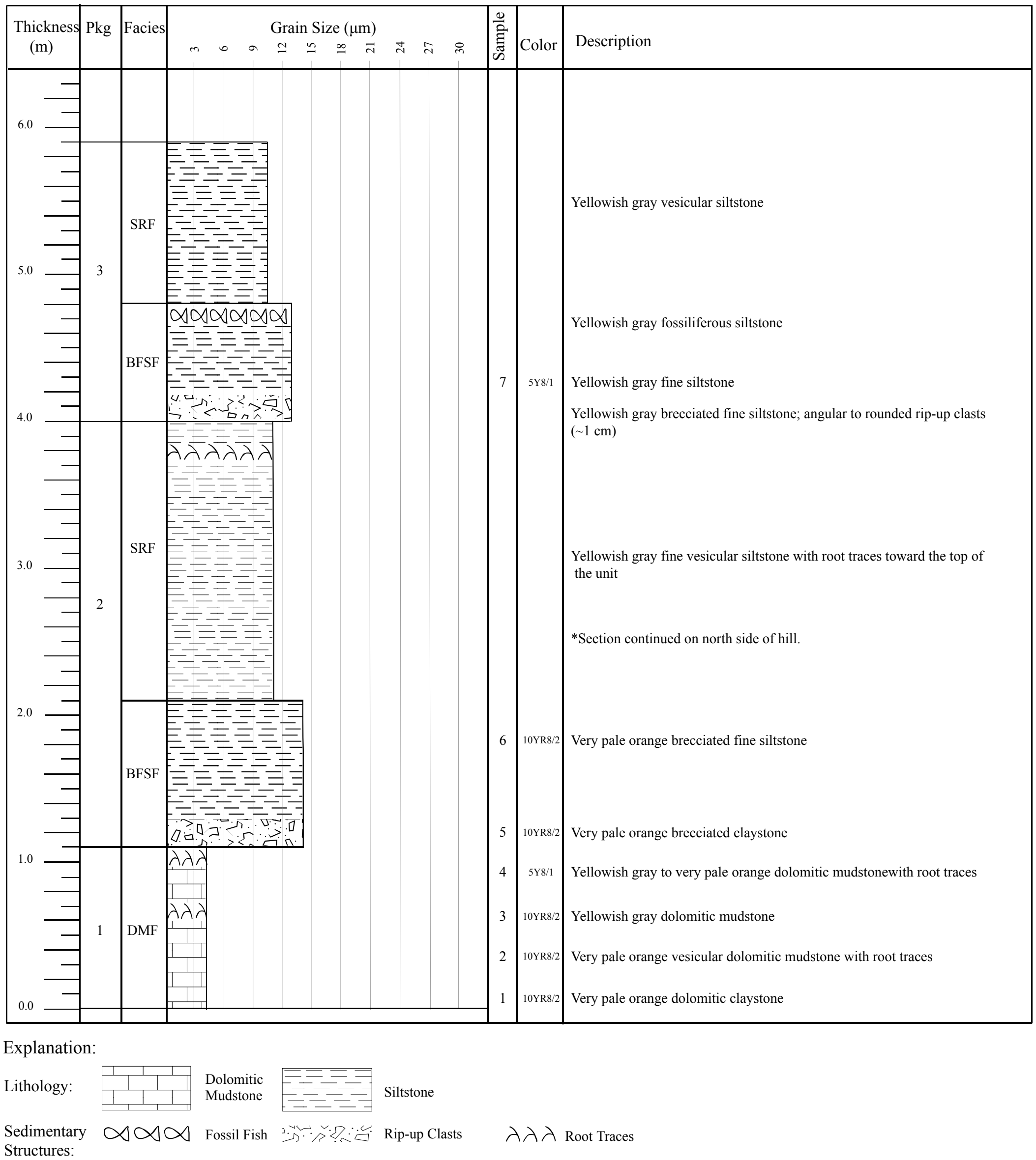

Thickness (m)
Pkg
Facies
Grain Size (µm)
3 6 9 12 15 18 21 24 27 30
Sample
Color
Description
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3
2
1
SRF
BFSF
SRF
BFSF
DMF
Yellowish gray vesicular siltstone
Yellowish gray fossiliferous siltstone
7
5Y8/1
Yellowish gray fine siltstone
Yellowish gray brecciated fine siltstone; angular to rounded rip-up clasts (~1 cm)
Yellowish gray fine vesicular siltstone with root traces toward the top of the unit
*Section continued on north side of hill.
6
10YR8/2
Very pale orange brecciated fine siltstone
5
10YR8/2
Very pale orange brecciated claystone
4
5Y8/1
Yellowish gray to very pale orange dolomitic mudstonewith root traces
3
10YR8/2
Yellowish gray dolomitic mudstone
2
10YR8/2
Very pale orange vesicular dolomitic mudstone with root traces
1
10YR8/2
Very pale orange dolomitic claystone
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossil Fish
Rip-up Clasts
Root Traces

Figure 3.8: Stratigraphic column from STT section the Etadunna Formation.

STT Section

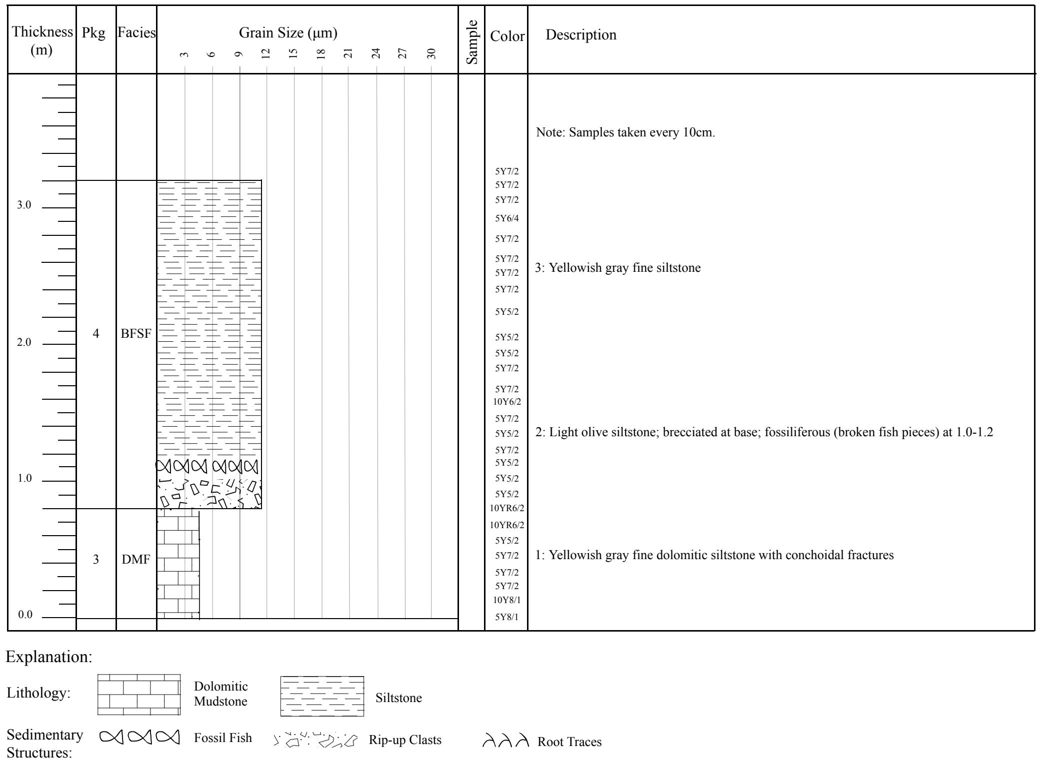

Thickness (m)
Pkg
Facies
Grain Size (μm)
3 6 9 12 15 18 21 24 27 30
Sample
Color
Description
3.0
2.0
1.0
0.0
4
BFSF
3
DMF
5Y7/2
5Y7/2
5Y7/2
5Y6/4
5Y7/2
5Y7/2
5Y7/2
5Y7/2
5Y5/2
5Y5/2
5Y5/2
5Y7/2
5Y7/2
10Y6/2
5Y7/2
5Y5/2
5Y7/2
5Y5/2
5Y5/2
5Y5/2
10YR6/2
10YR6/2
5Y5/2
5Y7/2
5Y7/2
5Y7/2
10Y8/1
5Y8/1
Note: Samples taken every 10cm.
3: Yellowish gray fine siltstone
2: Light olive siltstone; brecciated at base; fossiliferous (broken fish pieces) at 1.0-1.2
1: Yellowish gray fine dolomitic siltstone with conchoidal fractures
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossil Fish
Rip-up Clasts
Root Traces

Figure 3.9: Fence diagram of stratigraphic columns from sections SSB, SYB, SCQ, and STT of the Etadunna Formation.

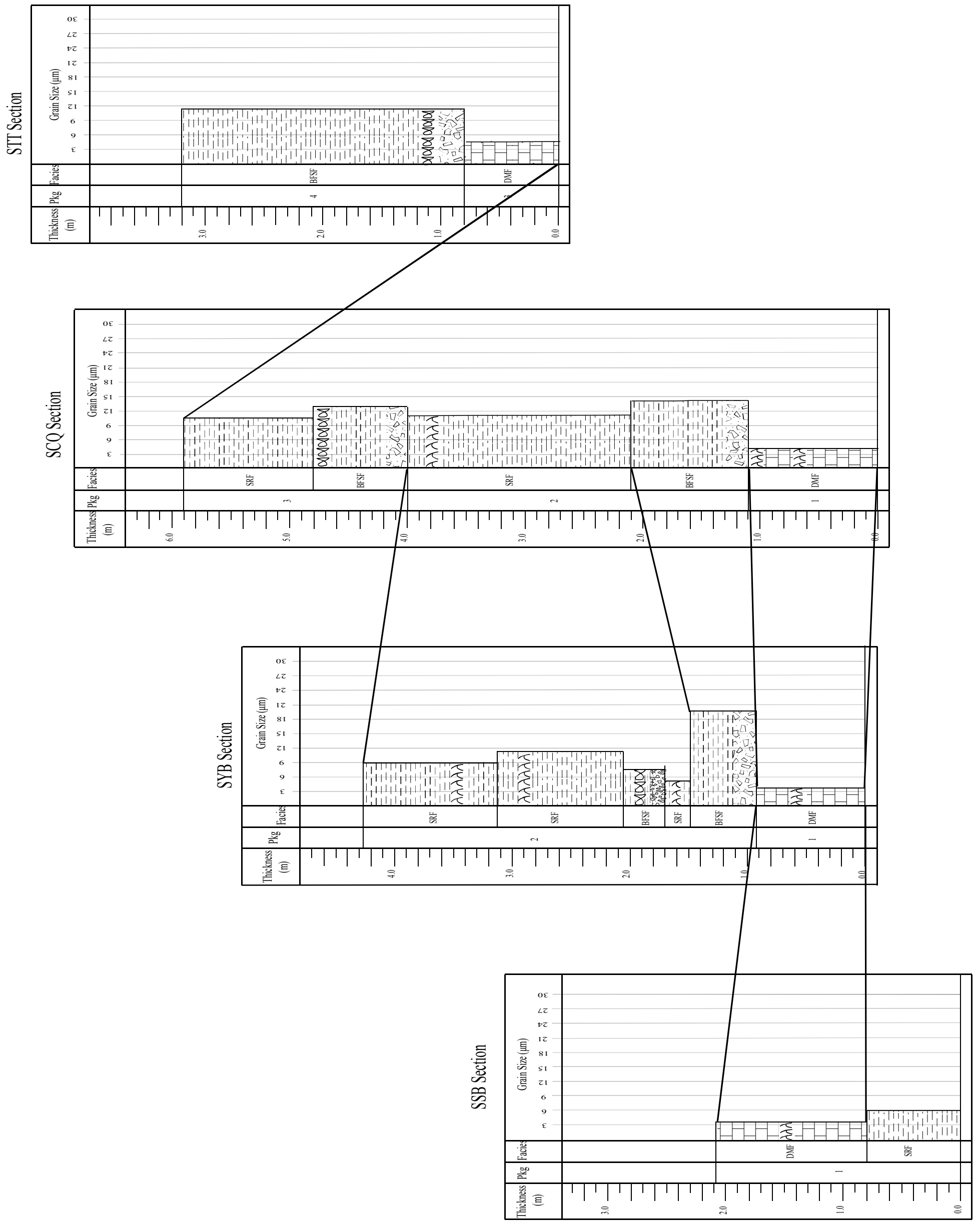
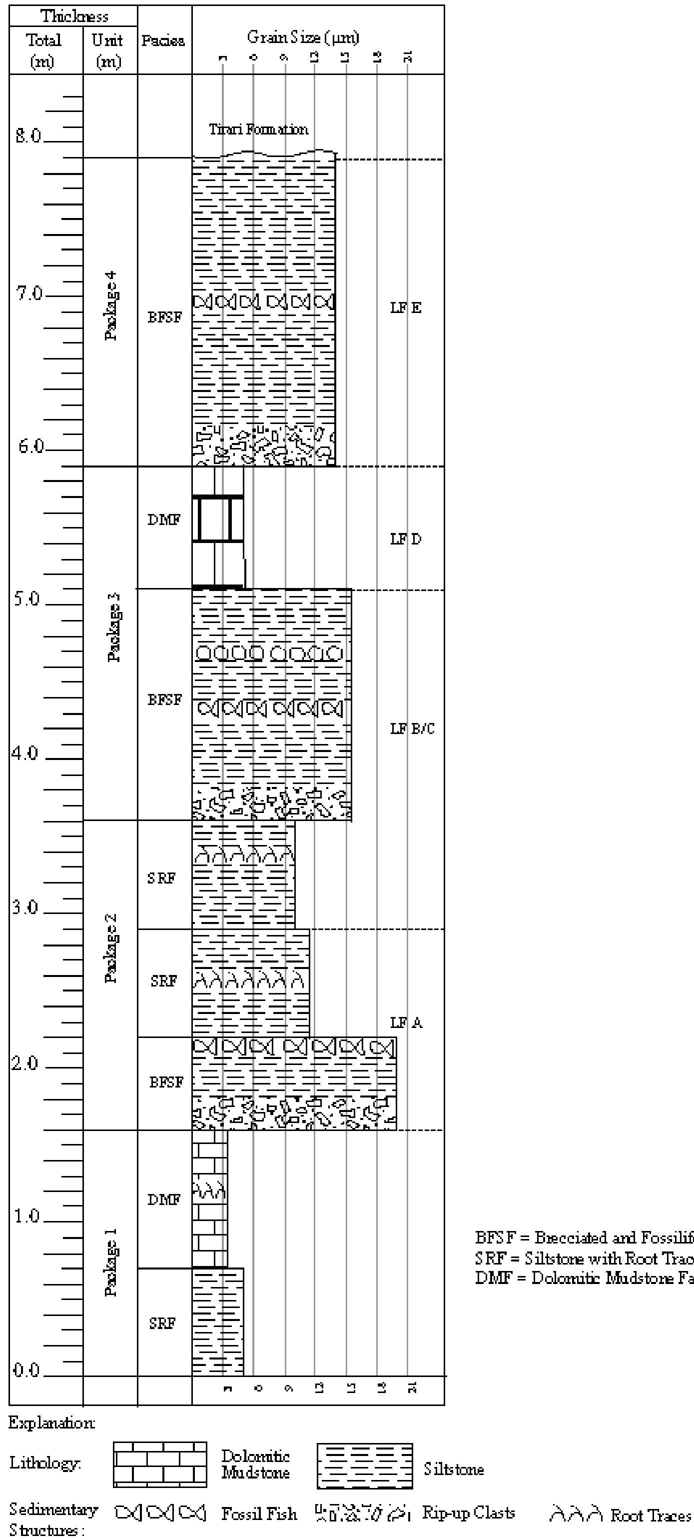

STT Section
SCQ Section
SYB Section
SSB Section
Grain Size (μm)
Facies
Pkg
Thickness (m)
BFSF
DMF
SRF

Figure 3.10: Composite stratigraphic section of the Etadunna Formation at Lake Palankarinna, South Australia. SRF: Siltstone with Root Traces Facies; DMF: Dolomitic Mudstone Facies; BFSF: Brecciated and Fossiliferous Siltstone Facies.



BFSF = Brecciated and Fossiliferous Siltstone Facies
SRF = Siltstone with Root Traces Facies
DMF = Dolomitic Mudstone Facies

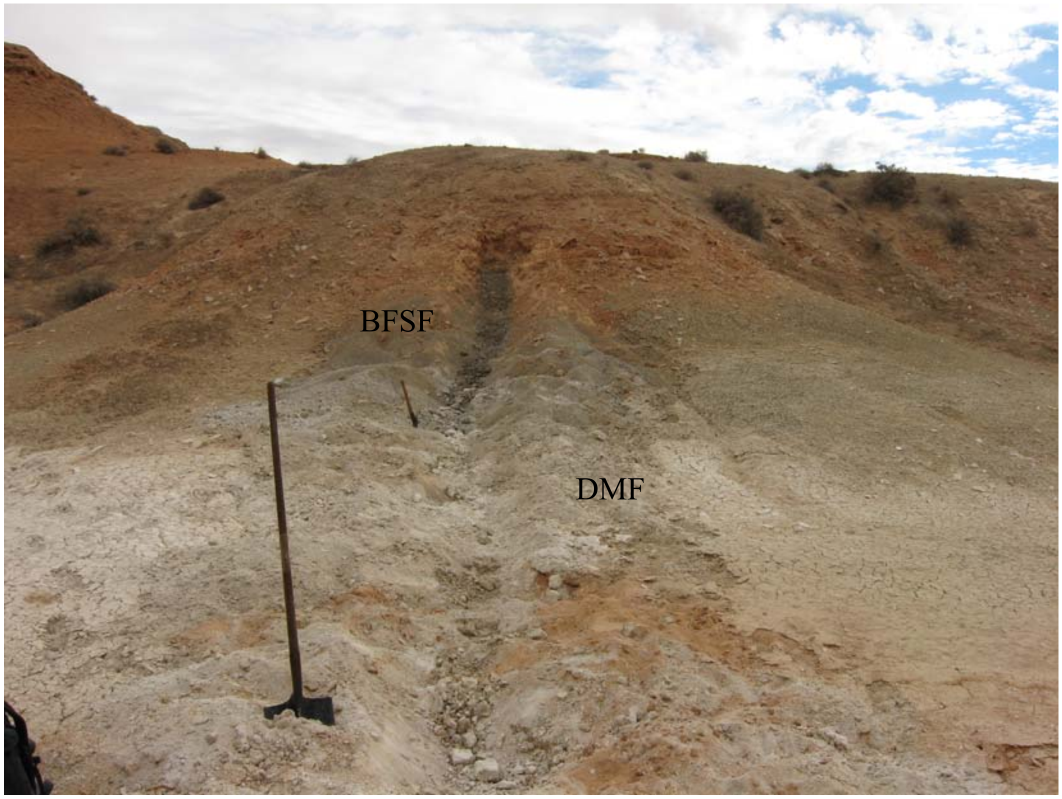


Figure 3.11: Example of trench dug for lithologic description. The lower, lighter unit is of the Dolomitic Mudstone Facies (DMF) of Package 3. The upper green unit is part of the Brecciated and Fossiliferous Siltstone Facies (BFSF) of Package 4.

Figure 3.12: Examples of facies from the Etadunna Formation. A) Dolomitic Mudstone Facies, with root traces; B) Siltstone with Root Traces Facies; C) Brecciated and Fossiliferous Siltstone Facies. Arrows in C indicate rip-up clasts.
All scale bars are 1 cm.

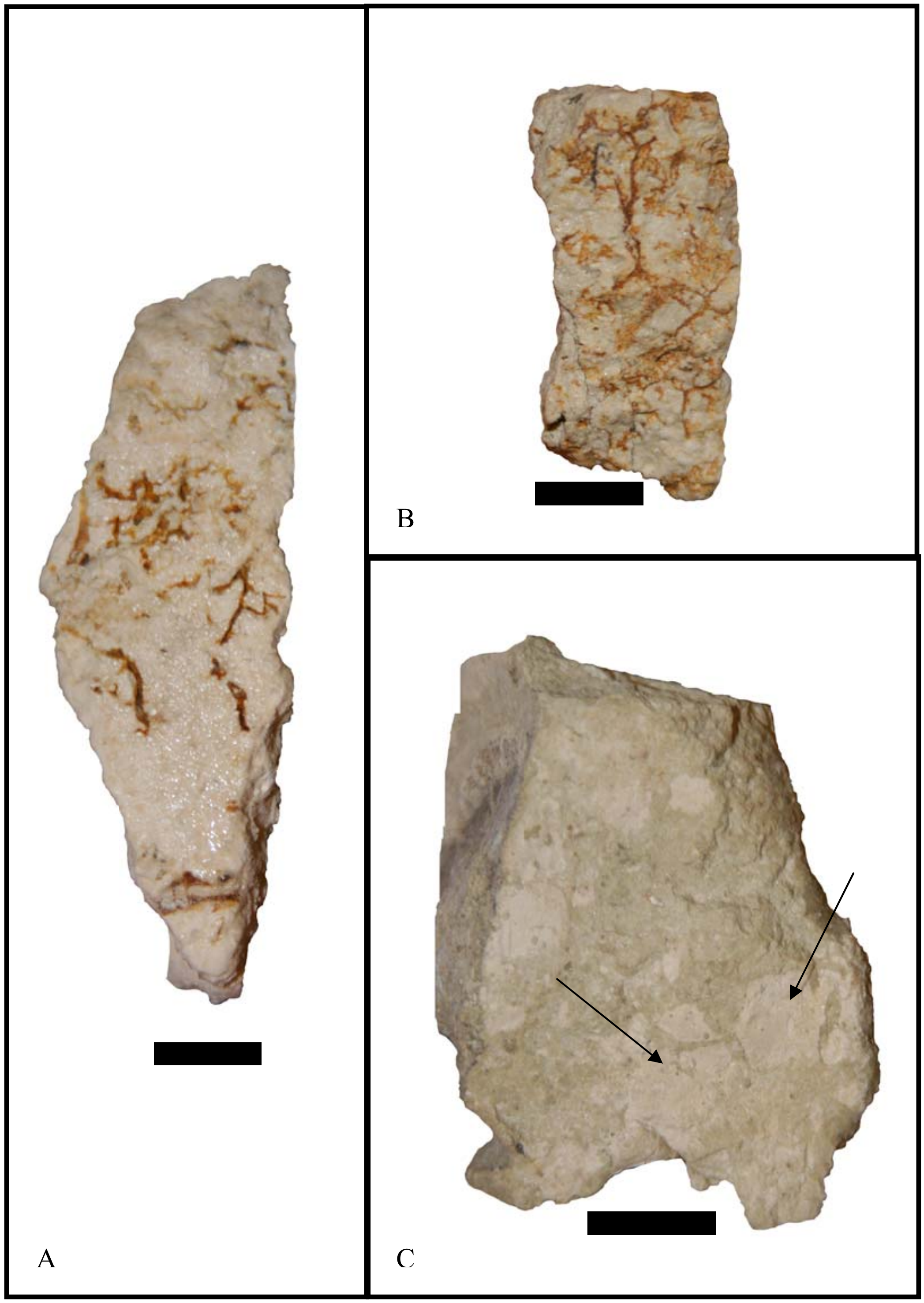

B
A
C

Figure 3.13: Idealized stratigraphic section of a single package of the Etadunna Formation showing the wetting and drying phases of the lake system. BFSF: Brecciated and Fossiliferous Siltstone Facies; SRF: Siltstone with Root Traces Facies; DMF: Dolomitic Mudstone Facies.

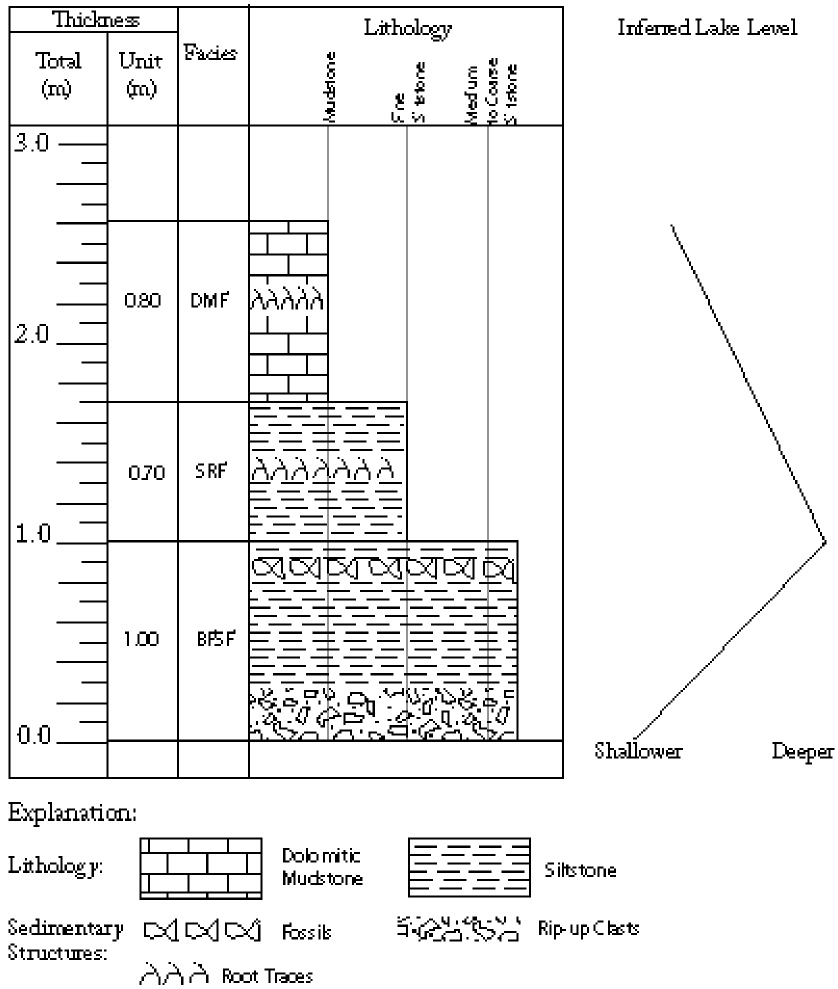

Thickness
Total (m)
Unit (m)
Facies
Lithology
Mudstone
Fine Siltstone
Medium to Coarse Siltstone
Inferred Lake Level
3.0
2.0
1.0
0.0
0.80
DMF
0.70
SRF
1.00
BFSF
Shallower
Deeper
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossils
Rip-up Clasts
Root Traces

Figure 3.14: Summary figure of Etadunna Formation facies with generic abundance and eco-group abundances.

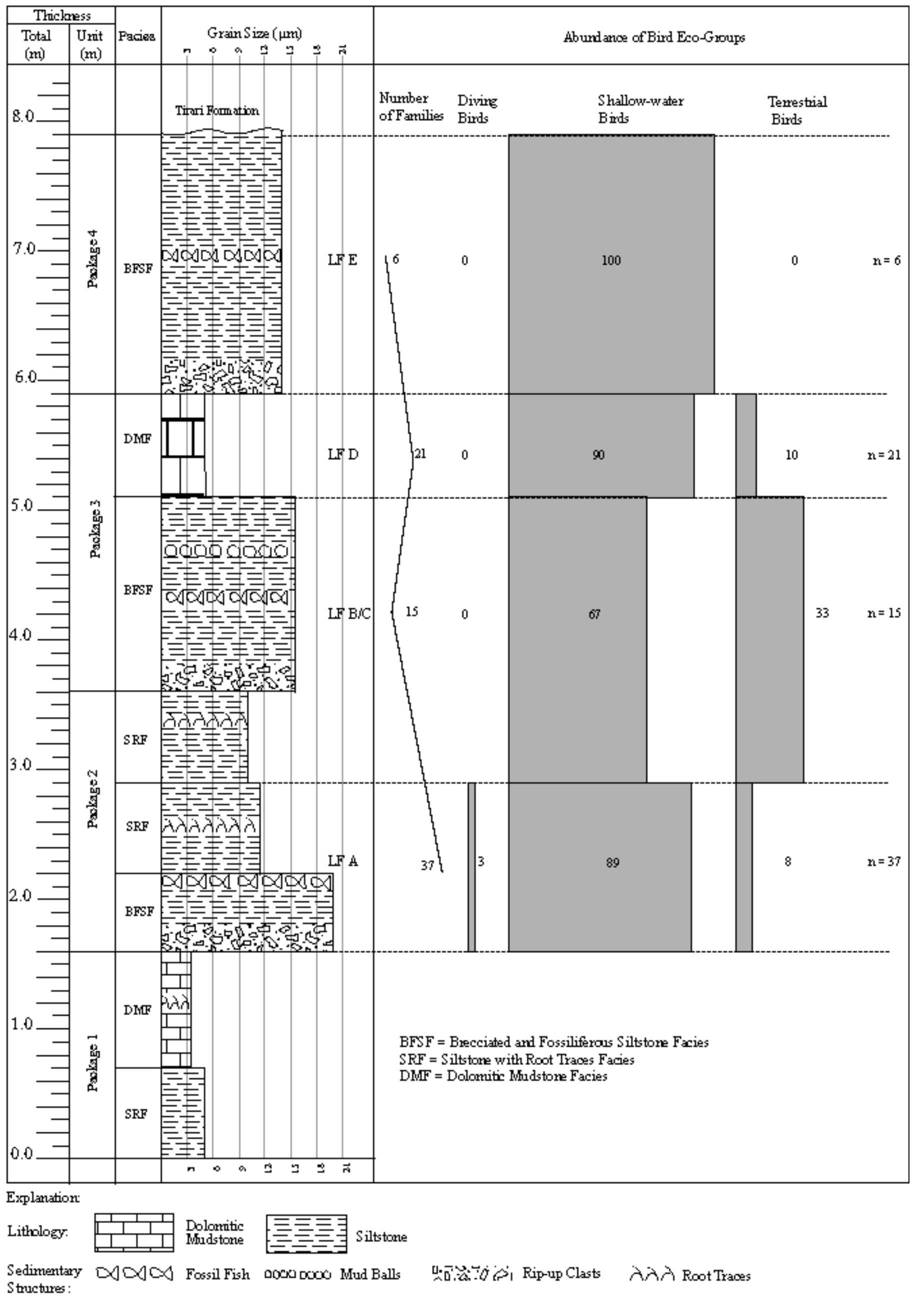

Thickness
Total (m)
Unit (m)
Facies
Grain Size (μm)
Abundance of Bird Eco-Groups
Number of Families
Diving Birds
Shallow-water Birds
Terrestrial Birds
Tirari Formation
Package 4
Package 3
Package 2
Package 1
BFSF
DMF
SRF
LF E
LF D
LF B/C
LF A
n = 6
n = 21
n = 15
n = 37
BFSF = Brecciated and Fossiliferous Siltstone Facies
SRF = Siltstone with Root Traces Facies
DMF = Dolomitic Mudstone Facies
Explanation:
Lithology:
Dolomitic Mudstone
Siltstone
Sedimentary Structures:
Fossil Fish
Mud Balls
Rip-up Clasts
Root Traces

Plate 3.1: Galliformes (A); Anseriformes (B-D)
A: JEH006: Phasianidae, Distal humerus, caudal view.
B: JEH007A: Anatidae, Proximal coracoid, dorsal view.
C: 22712: Anatidae, Distal femur, caudal view.
D: 16082: Anatidae, Distal tibiotarsus, plantar view.
All scale bars = 1 cm.

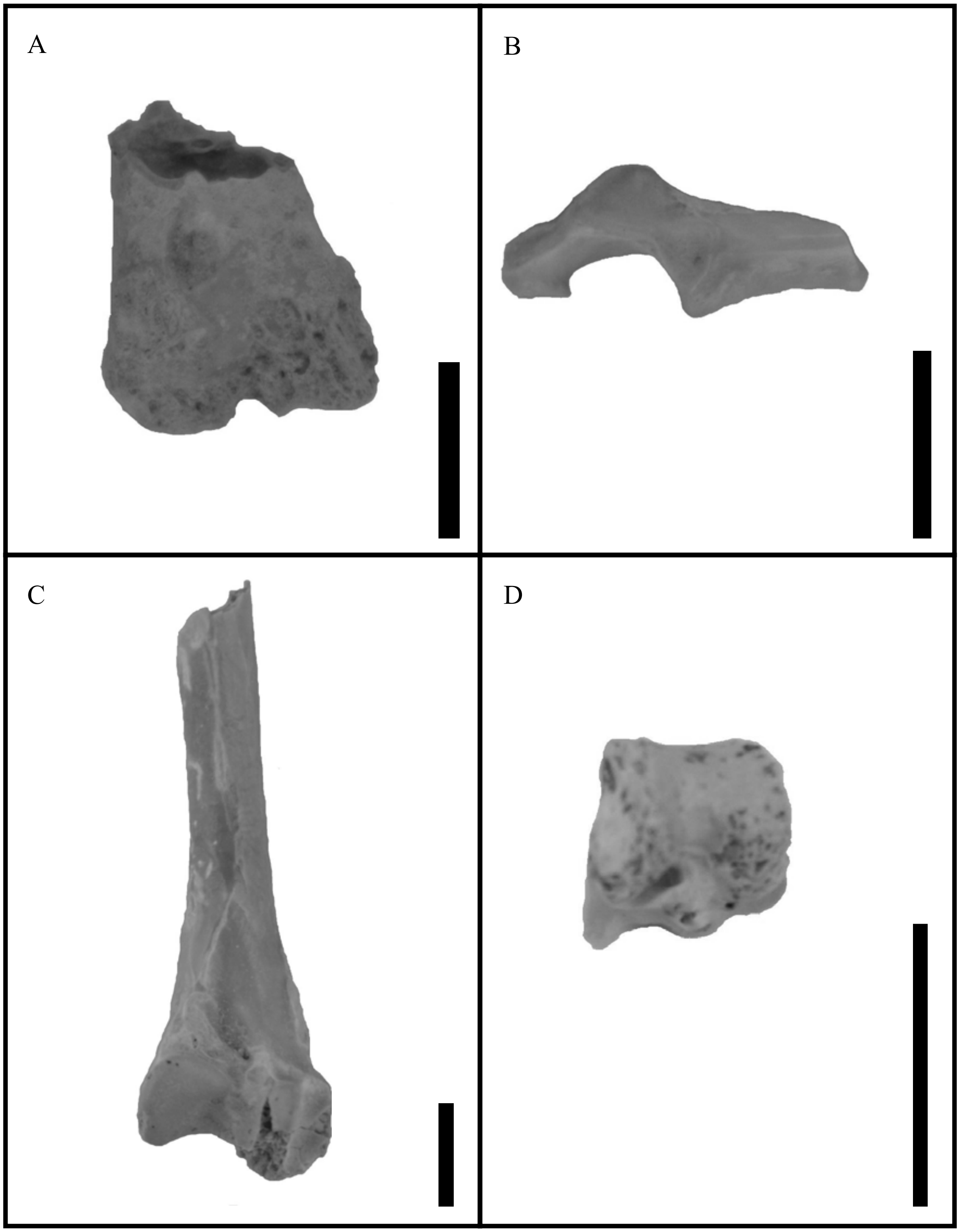

A
B
C
D

Plate 3.2: Procellariiformes (A); Pelecaniformes (B); Ciconiiformes (C)
A: YBQ01-09: ?*Diomedea*, Distal tibiotarsus, medial view.
B: JEH005: *Phalacrocorax*, Proximal scapula, lateral view.
C: JEH011A: *Palaelodus*, Distal ulna, caudal view.
All scale bars = 1 cm.

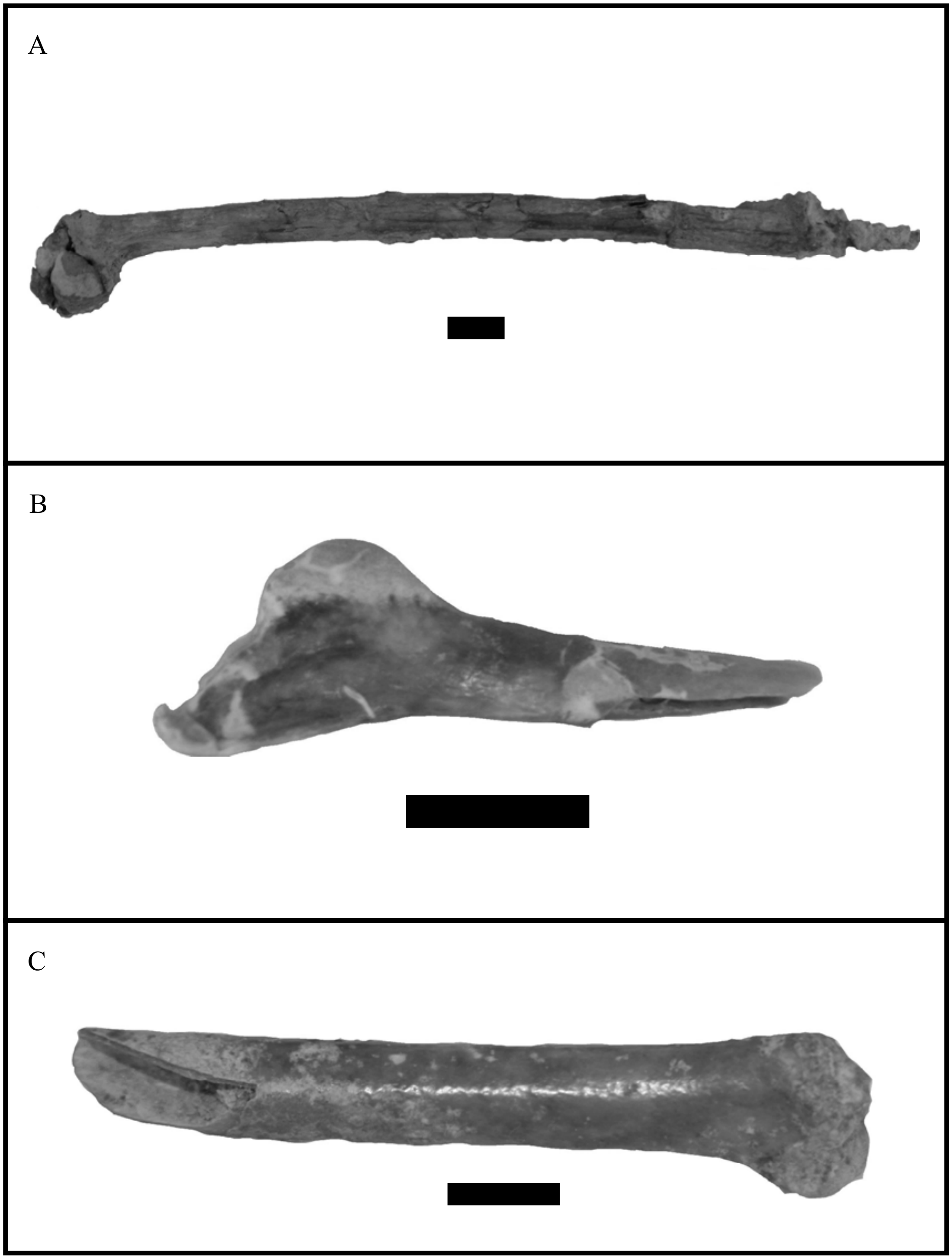

A
B
C

Plate 3.3: Ciconiiformes
A: 22037: *Palaelodus*, Distal tibiotarsus, cranial view.
B: 33046: *Palaelodus*, Distal tarsometatarsus, dorsal view.
C: 22306: *Phoenicopterus*, Distal ulna, caudal view.
All scale bars = 1 cm.

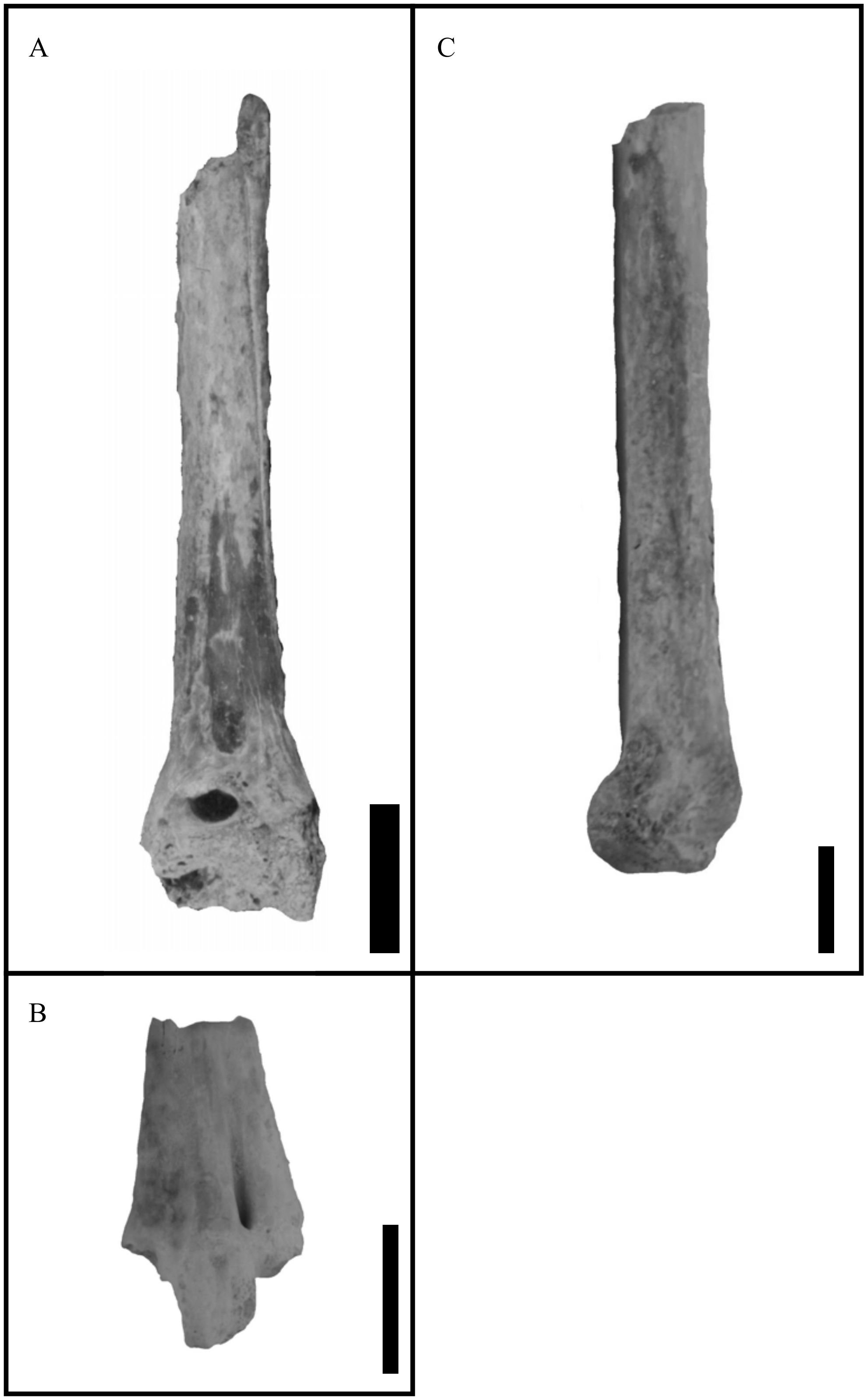

A
C
B

Plate 3.4: Ciconiiformes (A-B); Gruiformes (C); Ralliformes (D)
A: JEH010C: *Phoenicopterus*, Proximal carpometacarpus, ventral view.
B: 21893: ?*Eudocimus*, Distal tibiotarsus, cranial view.
C: VP0703: ?Guidae, Proximal tarsometatarsus, dorsal view.
D: 22711: Rallidae, Distal humerus, caudal view.
All scale bars = 1 cm.


A
B
C
D

Plate 3.5: Charadriiformes
A: JEH007C: Charadriiformes, Proximal carpometacarpus, ventral view.
B: JEH009B: *Recurvirostra* sp., Tarsometatarsus, dorsal view.
C: JEH009B: *Recurvirostra* sp., Tarsometatarsus, plantar view.

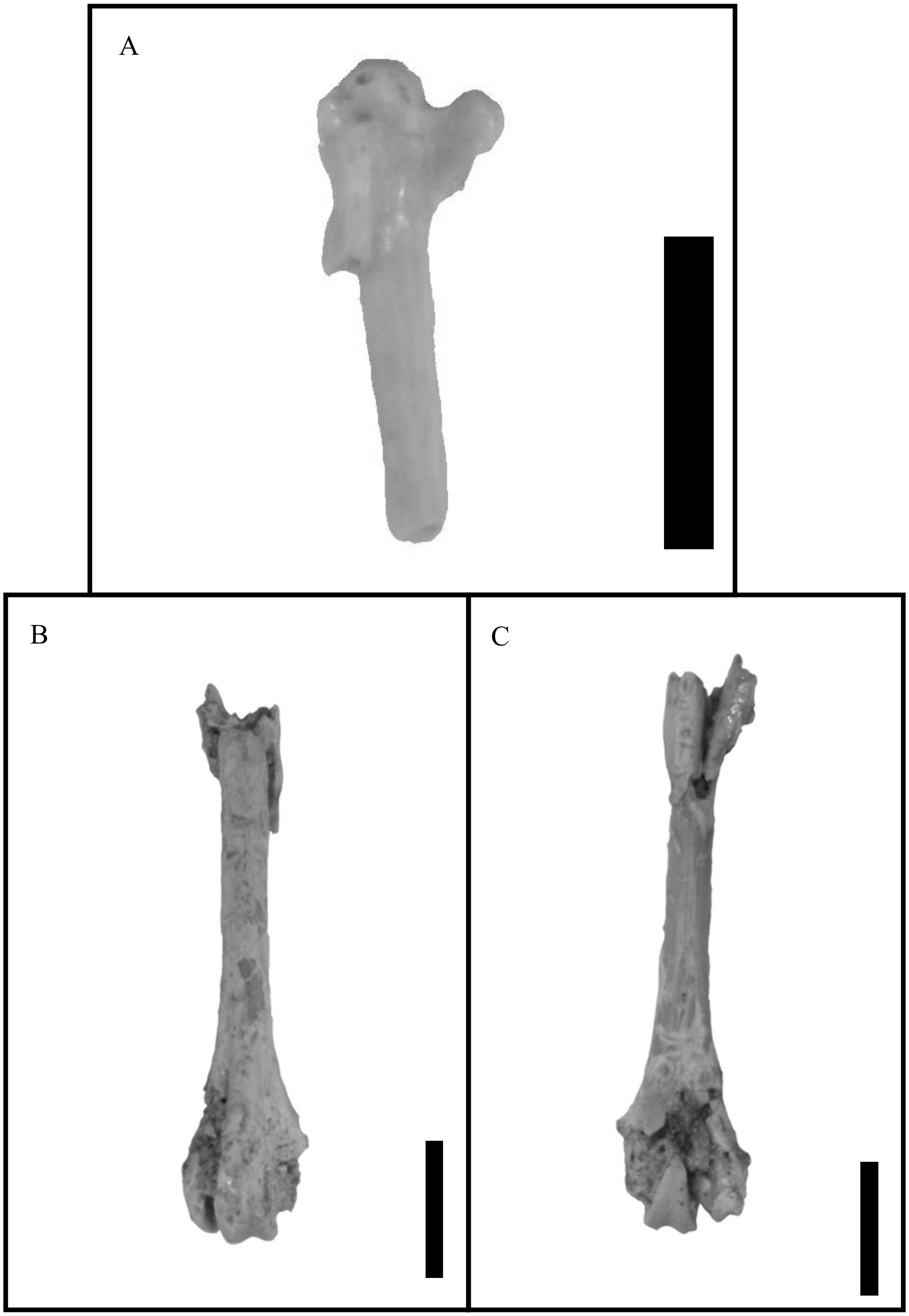
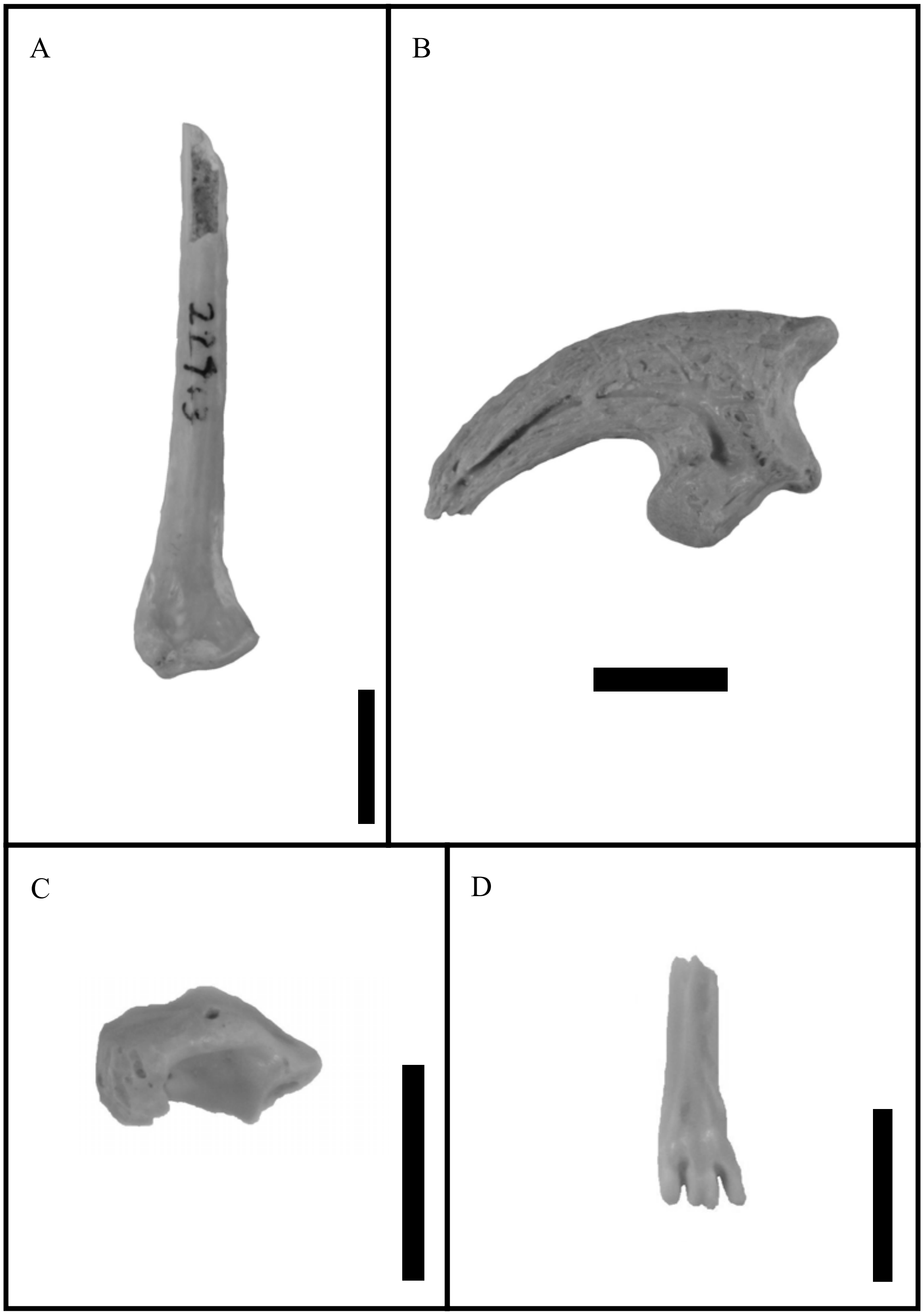

A
B
C

Plate 3.6: Falconiformes (A, B); Psittaciformes (C); Passeriformes (D)
A: 22713: Accipitridae, Distal radius, caudal view.
B: VP0365: Accipitriidae. Ungual.
C: 16095B: *Cacatua* sp., Proximal coracoid, dorsal view.
D: JEH007: Corvidae, Distal tarsometarsus, dorsal view.



A
B
C
D

CHAPTER 4: SUMMARY

Facies analyses of sedimentary deposits are utilized to determine depositional models as well as temporal changes in environments. Depositional environments were inferred from facies analyses of both the Pleistocene Fossil Lake Formation of Oregon, and the Oligocene Etadunna Formation of South Australia. Although both formations exhibit packages of upwardly fining sequences (Fossil Lake: Allison, 1979; Martin et al., 2005; Etadunna: Stirton et al., 1961; Woodburne et al, 1993), the packages resulted from different mechanisms. Each package of the Fossil Lake Formation generally records a gradual increase in lake water level followed by an abrupt drop in lake water level and subsequent exposure. Each package of the Etadunna Formation, however, records a rapid increase in lake water level, followed by a gradual decrease in water depth, as evidenced by a shallowing-up lithologic trend. The Mudstone Facies is the finest-grained facies of the Fossil Lake Formation and is interpreted as reflecting offshore deposition, based on the presence of associated skeletons of fossil cyprinid and salmonid fish. In the Etadunna Formation, the finest-grained facies is the Dolomitic Mudstone Facies, which is interpreted to have formed under nearshore, evaporitic conditions, as determined by the presence of dolomite and abundant wading bird fossils.

Although the packages of both formations resulted from different mechanisms, both lake systems were ultimately controlled by climate. The Fossil Lake Formation was deposited during the Pleistocene and experienced oscillations as the climate fluctuated during and between glacial and interglacial conditions. The Etadunna Formation at Lake Palankarinna was deposited during the Oligocene as regional flooding rapidly filled the Lake Eyre Basin and then slowly shallowed as a result of the regional arid climate. Both formations record abrupt changes in water levels that record the rapidity of climatic change (Bond et al., 1993; Woodburne et al., 1993) and discontinuous sedimentation. Therefore, smooth transitions in the stratigraphy and in fossil avifauna are not recorded.

Although birds often have large ranges and often migrate, fossil avifauna can still provide information on past climatic conditions. Non-migratory species or species with small ranges would be most useful in paleoclimatic studies. This study showed that the separation of the fossil avifauna into eco-groups of known habitat preferences, such as diving birds, shallow-water birds, and terrestrial birds, does allow for comparisons between the groups if the sample size is sufficient. Changes in abundances and occurrences of eco-groups through a stratigraphic section may reflect changes in climate and/or habitat. In the Fossil Lake Formation, for example, diving birds are most abundant in finer-grained sediments, which, based on the facies analysis, represents a time when water levels were relatively deep. Diving birds are absent from the coarsest deposits which reflect shallower water depths that may not have been sufficient to sustain the habitat of these birds. Overall, the diversity of bird genera decrease from Packages 2-4, possibly reflecting the transition from wet to dry conditions. In the Etadunna Formation, there is an abundance of storks and flamingos, which prefer shallow-water environments, found in the paludal, Dolomitic Mudstone Facies.

Recommendations

Expansion of both study areas would allow for a better understanding of the lake systems. Currently, no pattern exists between the inferred depositional environments and site localities of the Fossil Lake Formation. These localities are clustered together and expanding sites throughout the Fort Rock Basin could help constrain depositional environments in a larger context, including fluvial input, which would also affect the abundances and diversity of the fossil fauna. In South Australia, comparisons of the more northerly lakes with the data from Lake Palankarinna may show small changes between depositional environments from different areas of the Lake Eyre Basin.

Examination of other fossil fauna, as well as the fossil flora, would help in determining the paleoenvironments of the lake systems. Pollen records would detail the type of vegetation from each facies, helping to reconstruct food sources, as well as water permanence. Fossil mammals could also be categorized into eco-groups to infer habitat. As with birds, mammal species with the smallest ranges or preferences for specific environments would be the most useful. A more complete reconstruction of the paleoclimatic conditions would be determined by comparing the occurrences and abundances of all of the available fossil data.

Currently, fossils from the Etadunna Formation are collected in accordance with local faunas, which span both packages and facies. Fossil collection from individual facies would allow for analysis of fossil abundances and diversity through time at a higher resolution.

Final Words

The use of fossil avifauna alone to constrain paleoclimatic conditions may be difficult as a result of preservational, sampling, and mobility biases. However, the addition of stratigraphically controlled collections of fossil avifauna within a lithostratigraphic framework, as I did in this investigation, have the potential to be used as broad climate indicators, such as in determining warm or cold and dry or wet conditions. Inclusion of all available data would produce the most complete paleoclimate history and is recommended.

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Appendix 1: Grain-size data for Fossil Lake Formation. S.D. = Standard deviation; d10 = 10^{th} percentile of grain size distribution; d90 = 90^{th} percentile of grain size distribution; Facies are as described in text: CSF = Conglomeratic Sandstone/Siltstone Facies; XSF = Cross-bedded Siltstone Facies; SF = Siltstone Facies; MF = Mudstone Facies.

Appendix 1: Grain Size Data for Fossil Lake Formation

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
FL 001	9.524	10.650	3.381	1.763	42.93	Fine Silt	MF
run 2	9.534	10.680	3.378	1.760	42.88	Fine Silt	MF
average	9.529	10.670	3.379	1.762	42.90	Fine Silt	MF
FL 002	30.150	46.960	4.693	2.944	152.50	Medium Silt	CSF
run 2	30.190	47.110	4.671	2.956	148.80	Medium Silt	CSF
average	30.170	47.040	4.682	2.950	150.70	Medium Silt	CSF
FL 003	9.773	10.250	3.776	1.608	55.87	Fine Silt	CSF
run 2	10.160	10.770	3.699	1.707	55.76	Fine Silt	CSF
average	9.964	10.510	3.738	1.656	55.81	Fine Silt	CSF
FL 004	4.099	4.224	3.172	0.878	18.40	Very Fine Silt	MF
run 2	4.304	4.504	3.016	0.976	17.88	Very Fine Silt	MF
average	4.200	4.367	3.095	0.925	18.13	Very Fine Silt	MF
FL 005	9.774	9.302	4.411	1.395	75.74	Fine Silt	CSF
run 2	10.480	10.030	4.408	1.487	80.54	Fine Silt	CSF
average	10.120	9.658	4.411	1.439	78.17	Fine Silt	CSF
FL 006	14.740	16.850	5.168	1.602	117.40	Fine Silt	SF
run 2	15.000	17.110	5.249	1.603	123.20	Fine Silt	SF
average	14.870	16.980	5.208	1.602	120.20	Fine Silt	SF
FL 007	88.880	208.600	6.775	2.844	415.90	Very Fine Sand	CSF
run 2	83.270	199.600	6.796	2.760	395.00	Very Fine Sand	CSF
average	86.030	204.100	6.787	2.801	404.50	Very Fine Sand	CSF
FL 008	10.370	10.770	4.613	1.313	70.63	Fine Silt	SF
run 2	10.290	10.920	4.495	1.324	67.23	Fine Silt	SF
average	10.330	10.840	4.554	1.319	68.76	Fine Silt	SF
FL 009	6.677	5.980	4.176	1.099	51.48	Very Fine Silt	CSF
run 2	6.731	6.063	4.173	1.103	51.33	Very Fine Silt	CSF
average	6.704	6.021	4.175	1.101	51.41	Very Fine Silt	CSF
FL 010	127.200	263.900	6.113	4.122	477.00	Fine Sand	CSF
run 2	125.200	261.600	6.160	4.087	479.50	Fine Sand	CSF
average	126.200	262.800	6.137	4.104	478.20	Fine Sand	CSF
FL 011	7.765	7.353	4.610	1.034	60.75	Very Fine Silt	SF
run 2	7.682	7.345	4.575	1.027	59.36	Very Fine Silt	SF
average	7.723	7.349	4.593	1.030	60.05	Very Fine Silt	SF
FL 012	53.280	119.200	6.466	2.629	315.20	Coarse Silt	CSF
run 2	53.920	120.400	6.473	2.649	318.30	Coarse Silt	CSF
average	53.600	119.800	6.470	2.639	316.80	Coarse Silt	CSF
FL 013	10.590	13.990	4.182	1.364	56.42	Fine Silt	SF
run 2	10.550	13.850	4.175	1.368	56.24	Fine Silt	SF
average	10.570	13.920	4.178	1.366	56.33	Fine Silt	SF

Appendix 1: Grain Size Data for Fossil Lake Formation, continued

Sample ID	**Mean**	**Median**	**S.D.**	**d10**	**d90**	**Classification**	**Facies**
FL 014	36.970	98.250	7.337	1.878	268.80	Coarse Silt	XSF
run 2	38.250	101.800	7.403	1.901	278.20	Coarse Silt	XSF
average	37.600	100.100	7.371	1.889	273.70	Coarse Silt	XSF
FL 015	15.550	21.170	4.010	1.911	75.14	Medium Silt	XSF
run 2	15.630	21.210	4.018	1.915	76.07	Medium Silt	XSF
average	15.590	21.190	4.014	1.913	75.61	Medium Silt	XSF
FL 016	4.692	5.287	2.824	1.113	16.61	Very Fine Silt	MF
run 2	4.679	5.286	2.831	1.108	16.56	Very Fine Silt	MF
average	4.686	5.286	2.828	1.110	16.59	Very Fine Silt	MF

Appendix 2: Fossil avifauna with locality and lithologic data from the Fossil Lake Formation.

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2

Spec. #	Element	Order	Family
SDSM 31289	Ulna (proximal, left)	Anseriformes	Anatidae
SDSM 30562a	Radius (distal)	Anseriformes	Anatidae
SDSM 30562b	Radius (distal)	Anseriformes	Anatidae
SDSM 31291	Carpometacarpus (right)	Anseriformes	Anatidae
SDSM 30567	Tarsometatarsus (left)	Anseriformes	Anatidae
SDSM 31288	Coracoid (distal, right)	Anseriformes	Anatidae
SDSM 30561	Radius (proximal)	Anseriformes	Anatidae
SDSM 30564	Ulna (proximal)	Anseriformes	Anatidae
SDSM 30557	Furcula	Anseriformes	Anatidae
SDSM 31287	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 31286	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 31290	Humerus (distal, left)	Podicipediformes	Podicipedidae
SDSM 30558	Humerus (left)	Charadriformes	Laridae
SDSM 30559	Humerus (right)	Charadriformes	Laridae
SDSM 30563	Ulna (proximal)	Passeriformes	Bombycillidae
SDSM 30565	Tibiotarsus (distal, right)	Passeriformes	Fringillidae
SDSM 31431	Coracoid (right)	Anseriformes	Anatidae
SDSM 28612	Scapula (left)	Anseriformes	Anatidae
SDSM 31425	Femur (proximal)	Podicipediformes	Podicipedidae
SDSM 28996	Premaxilla	Anseriformes	Anatidae
SDSM 29139	Humerus (proximal, left)	Anseriformes	Anatidae
SDSM 29148	Ulna (left)	Anseriformes	Anatidae
SDSM 29145	Humerus (distal, right)	Anseriformes	Anatidae
SDSM 29189a	Tibiotarsus (distal)	Anseriformes	Anatidae
SDSM 29189b	Tibiotarsus (distal)	Anseriformes	Anatidae
SDSM 29122	Coracoid (left)	Anseriformes	Anatidae
SDSM 29134	Scapula (right)	Anseriformes	Anatidae
SDSM 29117	Furcula	Anseriformes	Anatidae
SDSM 29132	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 29137	Humerus (proximal, left)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	Genus	Species	Locality Name	Locality #
SDSM 31289	*Anas*	*Anas americana*	Site b	V8934
SDSM 30562a	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 30562b	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 31291	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 30567	*Anas*	*Anas crecca*	Site b	V8934
SDSM 31288	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30561	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30564	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30557	*Clangula*	*Clangula hyemalis*	Site b	V8934
SDSM 31287	*Chen*	*Chen rossi*	Site b	V8934
SDSM 31286	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31290	*Podiceps*	*Podiceps nigricollis*	Site b	V8934
SDSM 30558	*Charadrius*	*Charadrius alexandrius*	Site b	V8934
SDSM 30559	*Charadrius*	*Charadrius alexandrius*	Site b	V8934
SDSM 30563	?*Bombycilla*	?*Bombycilla cedorum*	Site b	V8934
SDSM 30565	?	?	Site b	V8934
SDSM 31431	*Anas*	*Anas americana*	Site f	V891
SDSM 28612	*Branta*	*Branta canadensis*	Site f	V891
SDSM 31425	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 28996	?	?	Site g	V892
SDSM 29139	*Anas*	*Anas crecca*	Site g	V892
SDSM 29148	*Anas*	*Anas crecca*	Site g	V892
SDSM 29145	*Anas*	*Anas platyrhynchos*	Site g	V892
SDSM 29189a	*Anas*	*Anas platyrhynchos*	Site g	V892
SDSM 29189b	*Anas*	*Anas platyrhynchos*	Site g	V892
SDSM 29122	*Anas*	*Anas ?platyrhynchos*	Site g	V892
SDSM 29134	*Branta*	*Branta canadensis*	Site g	V892
SDSM 29117	*Branta*	*Branta canadensis*	Site g	V892
SDSM 29132	*Chen*	*Chen rossi*	Site g	V892
SDSM 29137	*Chen*	*Chen rossi*	Site g	V892

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	Element	Order	Family
SDSM 28943	Tibiotarsus (proximal)	Gaviiformes	Gaviidae
SDSM 29176	Femur (left)	Podicipediformes	Podicipedidae
SDSM 29177	Femur (proximal, right)	Podicipediformes	Podicipedidae
SDSM 29192	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 28995	Premaxilla	Passeriformes	Icteridae
SDSM 30121b	Coracoid (distal)	Galliformes	Phasianidae
SDSM 30177	Tarsometatarsus (proximal, left)	Galliformes	Phasianidae
SDSM 30082	Premaxilla	Anseriformes	Anatidae
SDSM 30137	Humerus (distal, right)	Anseriformes	Anatidae
SDSM 30145	Radius (proximal)	Anseriformes	Anatidae
SDSM 30122	Scapula (proximal)	Anseriformes	Anatidae
SDSM 30123	Scapula (proximal)	Anseriformes	Anatidae
SDSM 30124	Scapula (proximal)	Anseriformes	Anatidae
SDSM 30125a	Scapula (proximal)	Anseriformes	Anatidae
SDSM 30164	Femur (distal)	Anseriformes	Anatidae
SDSM 30173	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 30131	Scapula	Anseriformes	Anatidae
SDSM 30109	Coracoid (left)	Anseriformes	Anatidae
SDSM 30167	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 30117	Coracoid (proximal, left)	Anseriformes	Anatidae
SDSM 30119	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 30125b	Scapula (proximal)	Anseriformes	Anatidae
SDSM 30135	Humerus (proximal, right)	Anseriformes	Anatidae
SDSM 30141	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 30151	Ulna (distal, left)	Anseriformes	Anatidae
SDSM 30139	Humerus (distal)	Anseriformes	Anatidae
SDSM 30115	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 30116	Coracoid (proximal, left)	Anseriformes	Anatidae
SDSM 30121a	Coracoid (distal)	Anseriformes	Anatidae
SDSM 30144	Radius (proximal)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 28943	?	?	Site g	V892
SDSM 29176	*Aechmophorus*	*Aechmophorus occidentalis*	Site g	V892
SDSM 29177	*Aechmophorus*	*Aechmophorus occidentalis*	Site g	V892
SDSM 29192	*Aechmophorus*	*Aechmophorus occidentalis*	Site g	V892
SDSM 28995	*Xanthocephalus*	*Xanthocephalus xanthocephalus*	Site g	V892
SDSM 30121b	*Centrocercus*	*Centrocercus urophasianus*	Site h	V893
SDSM 30177	*Centrocercus*	*Centrocercus urophasianus*	Site h	V893
SDSM 30082	?	?	Site h	V893
SDSM 30137	?*Anas*	?	Site h	V893
SDSM 30145	?*Anas*	?	Site h	V893
SDSM 30122	*Anas*	*Anas americana*	Site h	V893
SDSM 30123	*Anas*	*Anas americana*	Site h	V893
SDSM 30124	*Anas*	*Anas americana*	Site h	V893
SDSM 30125a	*Anas*	*Anas americana*	Site h	V893
SDSM 30164	*Anas*	*Anas americana*	Site h	V893
SDSM 30173	*Anas*	*Anas americana*	Site h	V893
SDSM 30131	*Anas*	*Anas ?americana*	Site h	V893
SDSM 30109	*Anas*	*Anas clypeata*	Site h	V893
SDSM 30167	*Anas*	*Anas clypeata*	Site h	V893
SDSM 30117	*Anas*	*Anas crecca*	Site h	V893
SDSM 30119	*Anas*	*Anas crecca*	Site h	V893
SDSM 30125b	*Anas*	*Anas crecca*	Site h	V893
SDSM 30135	*Anas*	*Anas crecca*	Site h	V893
SDSM 30141	*Anas*	*Anas crecca*	Site h	V893
SDSM 30151	*Anas*	*Anas crecca*	Site h	V893
SDSM 30139	*Anas*	*Anas crecca*	Site h	V893
SDSM 30115	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30116	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30121a	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30144	*Anas*	*Anas platyrhynchos*	Site h	V893

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	**Element**	**Order**	**Family**
SDSM 30147	Radius (distal)	Anseriformes	Anatidae
SDSM 30155	Ulna (distal, right)	Anseriformes	Anatidae
SDSM 30159	Synsacrum	Anseriformes	Anatidae
SDSM 30172	Tibiotarsus (distal, left)	Anseriformes	Anatidae
SDSM 30176	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 30179	Tarsometatarsus (distal, right)	Anseriformes	Anatidae
SDSM 30128	Furcula	Anseriformes	Anatidae
SDSM 30180	Tarsometatarsus (distal, left)	Anseriformes	Anatidae
SDSM 30121c	Coracoid (distal)	Anseriformes	Anatidae
SDSM 30158	Synsacrum	Anseriformes	Anatidae
SDSM 30181	Tarsometatarsus (distal)	Anseriformes	Anatidae
SDSM 30136	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 30118	Coracoid (proximal, right)	Podicipediformes	Podicipedidae
SDSM 30129	Furcula	Podicipediformes	Podicipedidae
SDSM 30134	Humerus (proximal)	Podicipediformes	Podicipedidae
SDSM 30178	Tarsometatarsus (distal, right)	Podicipediformes	Podicipedidae
SDSM 30143	Radius (proximal)	Pelecaniformes	Phalacrocoracidae
SDSM 30149	Ulna (distal, right)	Pelecaniformes	Anhingidae
SDSM 30133	Humerus (proximal, right)	Ciconiiformes	Threskiornithidae
SDSM 30182	Tarsometatarsus (distal, right)	Charadriiformes	Scolopacidae
SDSM 30171	Tibiotarsus (proximal, left)	Charadriiformes	Scolopacidae
SDSM 30146	Radius (proximal)	Charadriiformes	Laridae
SDSM 30142	Radius	Falconiformes	Accipitridae
SDSM 30150	Ulna (distal, right)	Falconiformes	Falconidae
SDSM 30084	Ungual	Falconiformes	Accipitridae
SDSM 30166	Carpometacarpus (left)	Passeriformes	Corvidae
SDSM 30154	Ulna (proximal)	Passeriformes	Laniidae
SDSM 30152	Ulna (distal, right)	Passeriformes	Icteridae
SDSM 30153	Ulna (proximal, left)	Passeriformes	Icteridae
SDSM 30169	Carpometacarpus (proximal)	Passeriformes	?Fringillidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 30147	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30155	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30159	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30172	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30176	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30179	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 30128	*Branta*	*Branta bernicla*	Site h	V893
SDSM 30180	*Branta*	*Branta bernicla*	Site h	V893
SDSM 30121c	*Branta*	*Branta* sp.	Site h	V893
SDSM 30158	*Branta*	*Branta* sp.	Site h	V893
SDSM 30181	?*Branta*	?*Branta* sp.	Site h	V893
SDSM 30136	?*Chen*	*Chen* sp.	Site h	V893
SDSM 30118	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 30129	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 30134	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 30178	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 30143	*Phalacrocorax*	*Phalacrocorax auritus*	Site h	V893
SDSM 30149	*Anhinga*	*Anhinga anhinga*	Site h	V893
SDSM 30133	*Eudocimus*	*Eudocimus ruber*	Site h	V893
SDSM 30182	*Tringa*	*Tringa melanoleuca*	Site h	V893
SDSM 30171	?*Tringa*	?*Tringa* sp.	Site h	V893
SDSM 30146	*Sterna*	*Sterna forsteri*	Site h	V893
SDSM 30142	*Aquila*	*Aquila chrysaetos*	Site h	V893
SDSM 30150	*Falco*	*Falco* sp.	Site h	V893
SDSM 30084	?	?	Site h	V893
SDSM 30166	*Cyanocitta*	*Cyanocitta cristata*	Site h	V893
SDSM 30154	*Lanius*	*Lanius ludovicianus*	Site h	V893
SDSM 30152	*Sturnella*	*Sturnella neglecta*	Site h	V893
SDSM 30153	*Sturnella*	*Sturnella neglecta*	Site h	V893
SDSM 30169	?	?	Site h	V893

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	Element	Order	Family
SDSM 30174	Tibiotarsus (distal)	Passeriformes	Icteridae
SDSM 30120	Coracoid (proximal, right)	Passeriformes	?Fringillidae
SDSM 30132	Humerus	Passeriformes	?Vireonidae
SDSM 29523	Femur (associated)	Galliformes	Phasianidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 2, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 30174	?*Euphagus*	?*Euphagus* ?*cyanocephalus*	Site h	V893
SDSM 30120	?	?	Site h	V893
SDSM 30132	?*Vireo*	?*Vireo* sp.	Site h	V893
SDSM 29523	*Centrocercus*	*Centrocercus urophasianus*	Site cc	V8941

Appendix 2: Avifauna from the Mudstone Facies of Package 2

Spec. #	Element	Order	Family
SDSM 30862	Scapula (left)	Anseriformes	Anatidae
SDSM 30880	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 30859	Coracoid (right)	Anseriformes	Anatidae
SDSM 75813	Coracoid (right)	Anseriformes	Anatidae
SDSM 30863	Scapula (left)	Anseriformes	Anatidae
SDSM 30869	Humerus (distal, right)	Anseriformes	Anatidae
SDSM 30872	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 30860	Coracoid (proximal, left)	Anseriformes	Anatidae
SDSM 30881	Tarsometatarsus (distal, juvenile)	Anseriformes	Anatidae
SDSM 30916	Scapula	Anseriformes	Anatidae
SDSM 30870	Humerus (distal)	Podicipediformes	Podicipedidae
SDSM 30879	Femur (proximal)	Podicipediformes	Podicipedidae
SDSM 30875	Tibiotarsus (proximal)	Pelecaniformes	Anhingidae
SDSM 30868	Humerus (distal, left)	Gruiformes	Gruidae
SDSM 30871	Humerus (distal, left)	Ralliformes	Rallidae
SDSM 30864	Scapula (proximal, left)	Ralliformes	Rallidae
SDSM 30873	Humerus (distal, left)	Ralliformes	Rallidae
SDSM 30865	Scapula (proximal, left)	Charadriformes	Scolopacidae
SDSM 30927	Humerus (proximal, right)	Charadriformes	Charadriidae
SDSM 31957	Digit 2, phalanx 1	Galliformes	Phasianidae
SDSM 31958	Tibiotarsus (distal, left)	Galliformes	Phasianidae
SDSM 31951	Coracoid (proximal)	Anseriformes	Anatidae
SDSM 31950	Scapula (proximal, left)	Anseriformes	Anatidae
SDSM 31955	Radius (distal)	Anseriformes	Anatidae
SDSM 28601	Femur (left)	Podicipediformes	Podicipedidae
SDSM 31954	Ulna (distal, left)	Pelecaniformes	Anhingidae
SDSM 31956	Carpometacarpus (distal, right)	Falconiformes	Accipitridae
SDSM 28659	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 28894	Tibiotarsus	Galliformes	?
SDSM 28887	Carpometacarpus (left)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Mudstone Facies of Package 2, continued

Spec. #	Genus	Species	Locality Name	Locality #
SDSM 30862	*Anas*	*Anas americana*	Site b	V8934
SDSM 30880	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 30859	*Anas*	*Anas crecca*	Site b	V8934
SDSM 75813	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30863	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30869	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30872	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 30860	*Branta*	*Branta canadensis*	Site b	V8934
SDSM 30881	?*Branta*	?*Branta* sp.	Site b	V8934
SDSM 30916	?*Branta*	?*Branta* sp.	Site b	V8934
SDSM 30870	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 30879	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 30875	*Anhinga*	*Anhinga* sp.	Site b	V8934
SDSM 30868	*Grus*	*Grus ?canadensis*	Site b	V8934
SDSM 30871	*Fulica*	*Fulica americana*	Site b	V8934
SDSM 30864	*Fulica*	*Fulica americana*	Site b	V8934
SDSM 30873	*Fulica*	*Fulica americana*	Site b	V8934
SDSM 30865	?*Tringa*	?*Tringa* sp.	Site b	V8934
SDSM 30927	*Charadrius*	*Charadrius alexandrius*	Site b	V8934
SDSM 31957	*Centrocercus*	*Centrocercus urophasianus*	Site f	V891
SDSM 31958	*Centrocercus*	*Centrocercus urophasianus*	Site f	V891
SDSM 31951	?*Anas*	?*Anas* sp.	Site f	V891
SDSM 31950	*Anas*	*Anas americana*	Site f	V891
SDSM 31955	?*Branta*	?*Branta* sp.	Site f	V891
SDSM 28601	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 31954	?*Anhinga*	?*Anhinga* sp.	Site f	V891
SDSM 31956	*Circus*	*Circus cyaneus*	Site f	V891
SDSM 28659	*Chen*	*Chen rossi*	Site f (west)	V891
SDSM 28894	?	?	Site g	V892
SDSM 28887	*Anas*	*Anas* ?*clypeata*	Site g	V892

Appendix 2: Avifauna from the Mudstone Facies of Package 2, continued

Spec. #	Element	Order	Family
SDSM 28398	Femur (left)	Podicipediformes	Podicipedidae
SDSM 74772	Carpometacarpus (right)	Charadriiformes	Scolopacidae
SDSM 74807	Synsacrum	Galliformes	Phasianidae
SDSM 74810	Tibiotarsus (distal)	Anseriformes	Anatidae
SDSM 74802	Coracoid (proximal, left)	Anseriformes	Anatidae
SDSM 29958	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 74801	Coracoid (left)	Anseriformes	Anatidae
SDSM 74809	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 74808	Coracoid (left)	Anseriformes	Anatidae
SDSM 74806	Carpometacarpus (proximal)	Anseriformes	Anatidae
SDSM 74803	Coracoid (proximal, right)	Podicipediformes	Podicipedidae
SDSM 74804	Humerus (distal, left)	Podicipediformes	Podicipedidae
SDSM 74805	Carpometacarpus (right)	Charadriiformes	Scolopacidae
SDSM 29955	Humerus (left)	Charadriiformes	Laridae
SDSM 29956	Humerus (proximal)	Charadriiformes	Alcidae
SDSM 74799	Sternum	Strigiformes	Strigidae
SDSM 74818	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 74820	Tibiotarsus (distal, left)	Anseriformes	Anatidae
SDSM 75127	Humerus (proximal, right)	Anseriformes	Anatidae
SDSM 74822	Tasometatarsus (proximal; juvenile)	Anseriformes	Anatidae
SDSM 75126	Coracoid (distal, right)	Podicipediformes	Podicipedidae
SDSM 75128	Synsacrum	Podicipediformes	Podicipedidae
SDSM 74821	Tarometatarsus (right)	Pelecaniformes	Phalacrocoracidae
SDSM 75569	Femur (left)	Podicipediformes	Podicipedidae
SDSM 75570	Femur (right)	Podicipediformes	Podicipedidae
SDSM 31313	Humerus (proximal, right)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Mudstone Facies of Package 2, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 28398	*Aechmophorus*	*Aechmophorus occidentalis*	Site g	V892
SDSM 74772	*Tringa*	*Tringa melanoleuca*	Site g	V892
SDSM 74807	*Centrocercus*	*Centrocercus urophasianus*	Site h	V893
SDSM 74810	?*Anas*	?*Anas* sp.	Site h	V893
SDSM 74802	*Anas*	*Anas crecca*	Site h	V893
SDSM 29958	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 74801	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 74809	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 74808	*Branta*	*Branta canadensis*	Site h	V893
SDSM 74806	?*Branta*	?*Branta* ?*canadensis*	Site h	V893
SDSM 74803	*Podiceps*	*Podiceps nigricollis*	Site h	V893
SDSM 74804	*Podiceps*	*Podiceps nigricollis*	Site h	V893
SDSM 74805	*Tringa*	*Tringa melanoleuca*	Site h	V893
SDSM 29955	*Charadrius*	*Charadrius alexandrius*	Site h	V893
SDSM 29956	? *Uria*	?*Uria* sp.	Site h	V893
SDSM 74799	*Otus*	*Otus* ?*kennecotti*	Site h	V893
SDSM 74818	*Anas*	*Anas platyrhynchos*	Site j	V8914
SDSM 74820	*Anas*	*Anas platyrhynchos*	Site j	V8914
SDSM 75127	*Branta*	*Branta* sp.	Site j	V8914
SDSM 74822	*Cygnus*	*Cygnus olor*	Site j	V8914
SDSM 75126	*Aechmophorus*	*Aechmophorus occidentalis*	Site j	V8914
SDSM 75128	?*Aechmophorus*	*Aechmophorus* ?*occidentalis*	Site j	V8914
SDSM 74821	?*Phalacrocorax*	?*Phalacrocorax* sp.	Site j	V8914
SDSM 75569	*Aechmophorus*	*Aechmophorus occidentalis*	Site l	V895
SDSM 75570	*Aechmophorus*	*Aechmophorus occidentalis*	Site l	V895
SDSM 31313	*Anas*	*Anas americana*	Site c	V8939

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3

Spec. #	Element	Order	Family
SDSM 75501	Coracoid (distal, right)	Anseriformes	Anatidae
SDSM 75521a	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 75521b	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 33048	Scapula	Anseriformes	Anatidae
SDSM 33054c	Coracoid (proximal)	Anseriformes	Anatidae
SDSM 33059	Carpometacarpus (proximal, right)	Anseriformes	Anatidae
SDSM 33056	Ulna (proximal, right)	Anseriformes	Anatidae
SDSM 33058	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 33052	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 33053a	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 33053b	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 33054a	Coracoid (proximal)	Anseriformes	Anatidae
SDSM 33054b	Coracoid (proximal)	Anseriformes	Anatidae
SDSM 33049	Coracoid (left)	Anseriformes	Anatidae
SDSM 33065	Synsacrum	Anseriformes	Anatidae
SDSM 33042	Furcula	Anseriformes	Anatidae
SDSM 33044	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 33060	Digit 2, phalanx 1	Anseriformes	Anatidae
SDSM 33050	Coracoid (distal, right)	Anseriformes	Anatidae
SDSM 33047	Scapula (right)	Podicipediformes	Podicipedidae
SDSM 33057	Carpometacarpus (distal)	Podicipediformes	Podicipedidae
SDSM 33066a	Femur (distal)	Podicipediformes	Podicipedidae
SDSM 33066b	Femur (distal)	Podicipediformes	Podicipedidae
SDSM 33046	Scapula (proximal, left)	Pelecaniformes	Phalacrocoracidae
SDSM 74908a	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 74908b	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 74908c	Scapula (proximal, left)	Anseriformes	Anatidae
SDSM 75466	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 74931	Humerus (proximal, right)	Anseriformes	Anatidae
SDSM 74933	Humerus (distal, left)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Genus	Species	Locality Name	Locality #
SDSM 75501	*Anas*	*Anas platyrhynchos*	Site e	V8938
SDSM 75521a	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75521b	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 33048	?*Anas*	?*Anas* sp.	Site i	V894
SDSM 33054c	*Anas*	*Anas americana*	Site i	V894
SDSM 33059	*Anas*	*Anas* ?*americana*	Site i	V894
SDSM 33056	*Anas*	*Anas americana, smaller*	Site i	V894
SDSM 33058	*Anas*	*Anas clypeata*	Site i	V894
SDSM 33052	*Anas*	*Anas platyrhynchos*	Site i	V894
SDSM 33053a	*Anas*	*Anas platyrhynchos*	Site i	V894
SDSM 33053b	*Anas*	*Anas platyrhynchos*	Site i	V894
SDSM 33054a	*Anas*	*Anas platyrhynchos*	Site i	V894
SDSM 33054b	*Anas*	*Anas platyrhynchos*	Site i	V894
SDSM 33049	*Anas*	*Anas* ?*platyrhynchos*	Site i	V894
SDSM 33065	*Aythya*	*Aythya affinis*	Site i	V894
SDSM 33042	*Branta*	*Branta canadensis*	Site i	V894
SDSM 33044	*Branta*	*Branta canadensis*	Site i	V894
SDSM 33060	*Branta*	?*Branta* sp.	Site i	V894
SDSM 33050	?*Branta*	?*Branta* sp.	Site i	V894
SDSM 33047	*Aechmophorus*	*Aechmophorus occidentalis*	Site i	V894
SDSM 33057	*Aechmophorus*	*Aechmophorus occidentalis*	Site i	V894
SDSM 33066a	*Aechmophorus*	*Aechmophorus occidentalis*	Site i	V894
SDSM 33066b	*Aechmophorus*	*Aechmophorus occidentalis*	Site i	V894
SDSM 33046	*Phalacrocorax*	*Phalacrocorax auritus*	Site i	V894
SDSM 74908a	*Anas*	*Anas americana*	Site f	V891
SDSM 74908b	*Anas*	*Anas americana*	Site f	V891
SDSM 74908c	*Anas*	*Anas americana*	Site f	V891
SDSM 75466	*Anas*	*Anas americana*	Site f	V891
SDSM 74931	*Anas*	*Anas americana*	Site f	V891
SDSM 74933	*Anas*	*Anas americana*	Site f	V891

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Element	Order	Family
SDSM 74945	Ulna (left)	Anseriformes	Anatidae
SDSM 74979a	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 74979b	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 74976	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 74876	Basicranium	Anseriformes	Anatidae
SDSM 74930	Humerus (proximal, right)	Anseriformes	Anatidae
SDSM 74947	Carpometacarpus (right)	Anseriformes	Anatidae
SDSM 74905	Sternum	Anseriformes	Anatidae
SDSM 74929	Humerus (proximal, left)	Anseriformes	Anatidae
SDSM 74954	Synsacrum	Anseriformes	Anatidae
SDSM 74959	Synsacrum	Anseriformes	Anatidae
SDSM 74989a	Tarsometatarsus (distal, left)	Anseriformes	Anatidae
SDSM 74989b	Tarsometatarsus (distal, right)	Anseriformes	Anatidae
SDSM 74958	Synsacrum	Anseriformes	Anatidae
SDSM 74903a	Furcula fragment	Anseriformes	Anatidae
SDSM 74903b	Furcula fragment	Anseriformes	Anatidae
SDSM 74904	Sternum	Anseriformes	Anatidae
SDSM 74917	Coracoid (left)	Anseriformes	Anatidae
SDSM 75003	?Ulna (distal)	Anseriformes	Anatidae
SDSM 74915	Coracoid (right)	Anseriformes	Anatidae
SDSM 74925	Coracoid (proximal)	Anseriformes	Anatidae
SDSM 74972	Tibiotarsus (distal, left)	Anseriformes	Anatidae
SDSM 74973	Tibiotarsus (distal, left)	Anseriformes	Anatidae
SDSM 74965	Tibiotarsus (right)	Anseriformes	Anatidae
SDSM 74916	Coracoid (distal)	Podicipediformes	Podicipedidae
SDSM 74922b	Coracoid (proximal, right)	Podicipediformes	Podicipedidae
SDSM 74964	Femur (distal, right)	Podicipediformes	Podicipedidae
SDSM 74974	Tibiotarsus (distal, right)	Podicipediformes	Podicipedidae
SDSM 74986a	Tarsometatarsus (proximal, right)	Podicipediformes	Podicipedidae
SDSM 74986b	Tarsometatarsus (proximal, right)	Podicipediformes	Podicipedidae

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 74945	*Anas*	*Anas acuta*	Site f	V891
SDSM 74979a	*Anas*	*Anas americana*	Site f	V891
SDSM 74979b	*Anas*	*Anas americana*	Site f	V891
SDSM 74976	*Anas*	*Anas americana*	Site f	V891
SDSM 74876	*Anas*	*Anas ?americana*	Site f	V891
SDSM 74930	*Anas*	*Anas crecca*	Site f	V891
SDSM 74947	*Anas*	*Anas crecca*	Site f	V891
SDSM 74905	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74929	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74954	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74959	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74989a	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74989b	*Anas*	*Anas platyrhynchos*	Site f	V891
SDSM 74958	?*Anas*	*Anas ?platyrhynchos*	Site f	V891
SDSM 74903a	?*Branta*	?*Branta* sp.	Site f	V891
SDSM 74903b	?*Branta*	?*Branta* sp.	Site f	V891
SDSM 74904	*Branta*	*Branta* sp.	Site f	V891
SDSM 74917	*Branta*	*Branta* sp.	Site f	V891
SDSM 75003	?*Branta*	?*Branta* sp.	Site f	V891
SDSM 74915	*Branta*	*Branta bernicla*	Site f	V891
SDSM 74925	*Chen*	*Chen rossi*	Site f	V891
SDSM 74972	*Chen*	*Chen rossi*	Site f	V891
SDSM 74973	*Chen*	*Chen rossi*	Site f	V891
SDSM 74965	*Mergus*	*Mergus serrator*	Site f	V891
SDSM 74916	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74922b	?*Aechmophorus*	*Aechmophorus ?occidentalis*	Site f	V891
SDSM 74964	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74974	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74986a	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74986b	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	**Element**	**Order**	**Family**
SDSM 74990a	Tarsometatarsus (distal, left)	Podicipediformes	Podicipedidae
SDSM 74990b	Tarsometatarsus (distal, left)	Podicipediformes	Podicipedidae
SDSM 74932	Humerus (proximal)	Podicipediformes	Podicipedidae
SDSM 74982	Tarsometatarsus (right)	Podicipediformes	Podicipedidae
SDSM 74985	Tarsometatarsus (proximal, right)	Podicipediformes	Podicipedidae
SDSM 74918	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 74907	Sternum	Ardeiformes	Ardeidae
SDSM 74988	Tarsometatarsus (distal, right)	Ciconiiformes	Ardeidae
SDSM 74920	Coracoid (right)	Ralliformes	Rallidae
SDSM 74922a	Coracoid (proximal, right)	Ralliformes	Rallidae
SDSM 74919	Coracoid (left)	Falconiformes	?Accipitridae
SDSM 75002	Ungual	Falconiformes	Accipitridae

Appendix 2: Avifauna from the Mudstone Facies of Package 2 & Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 74990a	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74990b	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 74932	*Aechmophorus*	*Aechmophorus ?occidentalis*	Site f	V891
SDSM 74982	*Podiceps*	*Podiceps nigricollis*	Site f	V891
SDSM 74985	*Podilymbus*	*Podilymbus podiceps*	Site f	V891
SDSM 74918	*Podilymbus*	*Podilymbus podiceps*	Site f	V891
SDSM 74907	*Ardea*	*Ardea herodias*	Site f	V891
SDSM 74988	*Ardea*	*Ardea herodias*	Site f	V891
SDSM 74920	*Fulica*	*Fulica americana*	Site f	V891
SDSM 74922a	*Fulica*	*Fulica americana*	Site f	V891
SDSM 74919	?	?	Site f	V891
SDSM 75002	*Aquila*	*Aquila chrysaetos*	Site f	V891

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3

Spec. #	Element	Order	Family
SDSM 31180	Sternum	Anseriformes	Anatidae
SDSM 31183	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 75146	Coracoid (left)	Anseriformes	Anatidae
SDSM 31179	Sternum	Anseriformes	Anatidae
SDSM 31182	Scapula (proximal, left)	Anseriformes	Anatidae
SDSM 31195	Ulna (distal, left)	Anseriformes	Anatidae
SDSM 31198	Humerus (proximal, right)	Anseriformes	Anatidae
SDSM 31201	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 31210	Tarsometatarsus (proximal, left)	Anseriformes	Anatidae
SDSM 75572	Humerus (right, ventral)	Anseriformes	Anatidae
SDSM 31189	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 31194	Ulna (proximal, right)	Anseriformes	Anatidae
SDSM 31197	Ulna (distal, right)	Anseriformes	Anatidae
SDSM 30587	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 31196	Ulna (distal, left)	Anseriformes	Anatidae
SDSM 75171	Tarsometatarsus (left)	Anseriformes	Anatidae
SDSM 31191c	Coracoid (distal)	Anseriformes	Anatidae
SDSM 31199	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 31203	Synsacrum	Anseriformes	Anatidae
SDSM 75143	Sternum	Anseriformes	Anatidae
SDSM 30588	Ulna (distal, ulna)	Anseriformes	Anatidae
SDSM 75156	Radius (proximal)	Anseriformes	Anatidae
SDSM 31320	Tibiotarsus (distal, left)	Anseriformes	Anatidae
SDSM 31181	Scapula (proximal, left)	Anseriformes	Anatidae
SDSM 31187	Coracoid (proximal, left)	Anseriformes	Anatidae
SDSM 31205	Tibiotarsus (distal, right)	Anseriformes	Anatidae
SDSM 31212	Tarsometatarsus (distal)	Anseriformes	Anatidae
SDSM 75148a	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 75148b	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 75148c	Coracoid (right)	Podicipediformes	Podicipedidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 31180	*Anas*	*Anas* sp.	Site b	V8934
SDSM 31183	?*Anas*	?*Anas* sp.	Site b	V8934
SDSM 75146	*Anas*	*Anas americana*	Site b	V8934
SDSM 31179	*Anas*	*Anas americana*	Site b	V8934
SDSM 31182	*Anas*	*Anas americana*	Site b	V8934
SDSM 31195	*Anas*	*Anas americana*	Site b	V8934
SDSM 31198	*Anas*	*Anas americana*	Site b	V8934
SDSM 31201	*Anas*	*Anas americana*	Site b	V8934
SDSM 31210	*Anas*	*Anas americana*	Site b	V8934
SDSM 75572	*Anas*	*Anas* ?*americana*	Site b	V8934
SDSM 31189	*Anas*	*Anas crecca*	Site b	V8934
SDSM 31194	*Anas*	*Anas crecca*	Site b	V8934
SDSM 31197	*Anas*	*Anas crecca*	Site b	V8934
SDSM 30587	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 31196	*Anas*	*Anas clypeata*	Site b	V8934
SDSM 75171	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 31191c	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 31199	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 31203	*Anas*	*Anas* ?*platyrhynchos*	Site b	V8934
SDSM 75143	*Branta*	*Branta* sp.	Site b	V8934
SDSM 30588	?*Branta*	?*Branta* sp.	Site b	V8934
SDSM 75156	*Branta*	*Branta canadensis*	Site b	V8934
SDSM 31320	*Branta*	*Branta bernicla*	Site b	V8934
SDSM 31181	*Chen*	*Chen rossi*	Site b	V8934
SDSM 31187	*Branta*	*Branta canadensis*	Site b	V8934
SDSM 31205	*Branta*	*Branta bernicla*	Site b	V8934
SDSM 31212	?*Cygnus*	?*Cygnus olor*	Site b	V8934
SDSM 75148a	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75148b	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75148c	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Element	Order	Family
SDSM 75151a	Coracoid (distal, leftt)	Podicipediformes	Podicipedidae
SDSM 75151b	Coracoid (distal, right)	Podicipediformes	Podicipedidae
SDSM 31191b	Coracoid (distal)	Podicipediformes	Podicipedidae
SDSM 31185	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 31186	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 75147	Coracoid (left)	Podicipediformes	Podicipedidae
SDSM 75152	Humerus (proximal, left)	Podicipediformes	Podicipedidae
SDSM 75155	Humerus (distal, left)	Podicipediformes	Podicipedidae
SDSM 31192	Radius (distal)	Podicipediformes	Podicipedidae
SDSM 31202	Synsacrum	Podicipediformes	Podicipedidae
SDSM 75163	Femur (right)	Podicipediformes	Podicipedidae
SDSM 31204	Femur (right)	Podicipediformes	Podicipedidae
SDSM 75165	Tibiotarsus (proximal, right)	Podicipediformes	Podicipedidae
SDSM 75168a	Tibiotarsus (distal, left)	Podicipediformes	Podicipedidae
SDSM 75168b	Tibiotarsus (distal, right)	Podicipediformes	Podicipedidae
SDSM 75169	Tibiotarsus (distal)	Podicipediformes	Podicipedidae
SDSM 33014	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 31207	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 31211	Tarsometatarsus (distal, right)	Podicipediformes	Podicipedidae
SDSM 75153	Humerus (distal, right)	Podicipediformes	Podicipedidae
SDSM 75161	Synsacrum	Podicipediformes	Podicipedidae
SDSM 31191a	Coracoid (distal)	Podicipediformes	Podicipedidae
SDSM 31209	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 33015	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 75154	Humerus (distal, right)	Podicipediformes	Podicipedidae
SDSM 75162	Synsacrum	Pelecaniformes	Phalacrocoracidae
SDSM 75158	Ulna (distal)	Ardeiformes	Ardeidae
SDSM 31200	Carpometacarpus (proximal, left)	Ardeiformes	Ardeidae
SDSM 31193	Ulna (proximal,left)	Ralliformes	Rallidae
SDSM 31208	Tarsometatarsus (proximal, right)	Ralliformes	Rallidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Genus	Species	Locality Name	Locality #
SDSM 75151a	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75151b	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31191b	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31185	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31186	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75147	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75152	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75155	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31192	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31202	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75163	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31204	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75165	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75168a	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75168b	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75169	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 33014	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31207	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 31211	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75153	*Aechmophorus*	*Aechmophorus* ?*occidentalis*	Site b	V8934
SDSM 75161	*Aechmophorus*	*Aechmophorus* ?*occidentalis*	Site b	V8934
SDSM 31191a	*Podiceps*	*Podiceps auritus*	Site b	V8934
SDSM 31209	*Podiceps*	*Podiceps nigricollis*	Site b	V8934
SDSM 33015	*Podiceps*	*Podiceps nigricollis*	Site b	V8934
SDSM 75154	*Podilymbus*	*Podilymbus podiceps*	Site b	V8934
SDSM 75162	?*Phalacrocorax*	?*Phalacrocorax* ?*auritus*	Site b	V8934
SDSM 75158	*Ardea*	*Ardea herodias*	Site b	V8934
SDSM 31200	*Ardea*	*Ardea* ?*herodias*	Site b	V8934
SDSM 31193	?*Fulica*	?*Fulica* sp.	Site b	V8934
SDSM 31208	*Fulica*	*Fulica americana*	Site b	V8934

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Element	Order	Family
SDSM 31184	Coracoid (right)	Ralliformes	Rallidae
SDSM 30307	Coracoid (proximal, right)	Podicipediformes	Podicipedidae
SDSM 32969	Ulna (distal, right)	Anseriformes	Anatidae
SDSM 32965	Sternum	Anseriformes	Anatidae
SDSM 31436	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 32966	Coracoid (proximal,?right)	Anseriformes	Anatidae
SDSM 32967	Coracoid (proximal, right)	Podicipediformes	Podicipedidae
SDSM 32968	Humerus (distal, left)	Podicipediformes	Podicipedidae
SDSM 32972	Tarsometatarsus (distal, juvenile)	Podicipediformes	Podicipedidae
SDSM 32970	Digit 2, phalanx 1	Ardeiformes	Ardeidae
SDSM 75657a	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 30273	Furcula	Anseriformes	Anatidae
SDSM 30281	Tarsometatarsus (left)	Anseriformes	Anatidae
SDSM 30275	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 30276	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 30272	Furcula	Anseriformes	Anatidae
SDSM 75665	Syncacrum (acetabulae)	Anseriformes	Anatidae
SDSM 75196	Scapula	Anseriformes	Anatidae
SDSM 75657b	Coracoid (distal, right)	Anseriformes	Anatidae
SDSM 75660	Carpometacarpus (proximal, left)	Anseriformes	Anatidae
SDSM 75826	Coracoid (distal)	Anseriformes	Anatidae
SDSM 75834	Ulna (distal, right)	Anseriformes	Anatidae
SDSM 75672	Tarsometatarsus (right, juvenile)	Anseriformes	Anatidae
SDSM 75197	Humerus (distal, right)	Podicipediformes	Podicipedidae
SDSM 75632	Frontoparietals	Podicipediformes	Podicipedidae
SDSM 75653	Scapula (left)	Podicipediformes	Podicipedidae
SDSM 75669	Femur (distal, right)	Podicipediformes	Podicipedidae
SDSM 75633	Frontoparietals	Podicipediformes	Podicipedidae
SDSM 30270	Coracoid (left)	Ralliformes	Rallidae
SDSM 30271	Coracoid (right)	Ralliformes	Rallidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Genus	Species	Locality Name	Locality #
SDSM 31184	*Fulica*	*Fulica americana*	Site b	V8934
SDSM 30307	*Aechmophorus*	*Aechmophorus occidentalis*	Site i	V894
SDSM 32969	*Anas*	*Anas clypeata*	Site f	V891
SDSM 32965	*Anas*	*Anas ?platyrhynchos*	Site f	V891
SDSM 31436	*Branta*	*Branta canadensis*	Site f	V891
SDSM 32966	*Branta*	*Branta canadensis*	Site f	V891
SDSM 32967	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 32968	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 32972	*Aechmophorus*	*Aechmophorus occidentalis*	Site f	V891
SDSM 32970	*Ardea*	*Ardea herodias*	Site f	V891
SDSM 75657a	*Anas*	*Anas americana*	Site h	V893
SDSM 30273	*Anas*	*Anas americana*	Site h	V893
SDSM 30281	*Anas*	*Anas americana*	Site h	V893
SDSM 30275	*Anas*	*Anas clypeata*	Site h	V893
SDSM 30276	*Anas*	*Anas crecca*	Site h	V893
SDSM 30272	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 75665	*Anas*	*Anas platyrhynchos*	Site h	V893
SDSM 75196	*Branta*	*Branta canadensis*	Site h	V893
SDSM 75657b	*Branta*	*Branta canadensis*	Site h	V893
SDSM 75660	*Branta*	*Branta ?canadensis*	Site h	V893
SDSM 75826	*Branta*	*Branta ?canadensis*	Site h	V893
SDSM 75834	*Branta*	*Branta ?canadensis*	Site h	V893
SDSM 75672	*Branta*	*Branta* sp.	Site h	V893
SDSM 75197	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 75632	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 75653	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 75669	*Aechmophorus*	*Aechmophorus occidentalis*	Site h	V893
SDSM 75633	?*Aechmophorus*	*Aechmophorus ?occidentalis*	Site h	V893
SDSM 30270	*Fulica*	*Fulica americana*	Site h	V893
SDSM 30271	*Fulica*	*Fulica americana*	Site h	V893

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	Element	Order	Family
SDSM 28276	Humerus (proximal, left)	Anseriformes	Anatidae
SDSM 28418	Humerus (distal, left)	Anseriformes	Anatidae
SDSM 28269	Coracoid (proximal, right)	Anseriformes	Anatidae
SDSM 28259	Sternum	Anseriformes	Anatidae
SDSM 28422	Synsacrum	Podicipediformes	Podicipedidae
SDSM 28291	Tarsometatarsus (proximal)	Podicipediformes	Podicipedidae
SDSM 31277	Carpometacarpus (right)	Anseriformes	Anatidae
SDSM 31325	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 31326	Tarsometatarsus (distal, right)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 3, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 28276	?*Anas*	?*Anas* sp.	Site l	V895
SDSM 28418	*Anas*	*Anas crecca*	Site l	V895
SDSM 28269	*Anas*	*Anas smaller than crecca*	Site l	V895
SDSM 28259	?*Chen*	?*Chen* ?*rossi*	Site l	V895
SDSM 28422	*Aechmophorus*	*Aechmophorus occidentalis*	Site l	V895
SDSM 28291	*Aechmophorus*	*Aechmophorus occidentalis*	Site l	V895
SDSM 31277	*Anas*	*Anas americana*	Site d	V8939
SDSM 31325	*Anas*	*Anas platyrhynchos*	Site q (east)	V8915
SDSM 31326	*Athya*	*Athya affinis*	Site q (east)	V8915

Appendix 2: Avifauna from the Siltstone Facies of Package 3

Spec. #	Element	Order	Family
SDSM 75512	Radius (distal)	Anseriformes	Anatidae
SDSM 75510	Scapula (proximal, right)	Anseriformes	Anatidae
SDSM 75505	Associated radius/ulna (left)	Anseriformes	Anatidae
SDSM 75507	Femur (left)	Podicipediformes	Podicipedidae
SDSM 75511	Coracoid (distal, right)	Charadriiformes	Laridae

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 4

Spec. #	Element	Order	Family
SDSM 75138	Humerus (right)	Anseriformes	Anatidae

Appendix 2: Avifauna from the Siltstone Facies of Package 3, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 75512	*Anas*	*Anas platyrhynchos*	Site b	V8934
SDSM 75510	*Branta*	*Branta canadensis*	Site b	V8934
SDSM 75505	*Branta*	*Branta* sp.	Site b	V8934
SDSM 75507	*Aechmophorus*	*Aechmophorus occidentalis*	Site b	V8934
SDSM 75511	*Larus*	*Larus californicus*	Site b	V8934

Appendix 2: Avifauna from the Conglomeratic Sandstone/Siltstone Facies of Package 4, continued

Spec. #	**Genus**	**Species**	**Locality Name**	**Locality #**
SDSM 75138	*Anas*	*Anas platyrhynchos*	Site b	V8934

Appendix 3: Grain-size data for the Etadunna Formation. Grain-size data for Fossil Lake Formation. S.D. = Standard deviation; d10 = 10^{th} percentile of grain size distribution; d90 = 90^{th} percentile of grain size distribution; Facies are as described in text: BFSF = Brecciated and Fossiliferous Siltstone Facies; SRF = Siltstone with Root Traces Facies; DMF = Dolomitic Mudstone Facies.

Appendix 3: Grain Size Data for Etadunna Formation

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
SSB 0503b	4.053	4.180	3.748	0.807	21.68	Very Fine Silt	SRF
run 2	3.930	4.023	3.860	0.749	22.05	Very Fine Silt	SRF
average	3.991	4.103	3.804	0.777	21.87	Very Fine Silt	SRF
SSB 0503c	11.000	14.150	4.132	1.649	53.93	Fine Silt	SRF
run 2	10.470	13.290	4.105	1.606	51.13	Fine Silt	SRF
average	10.730	13.710	4.119	1.628	52.44	Fine Silt	SRF
SSB 0504a	4.987	3.515	6.015	0.546	54.76	Very Fine Silt	SRF
run 2	5.427	4.726	6.001	0.570	55.72	Very Fine Silt	SRF
average	5.202	4.065	6.011	0.558	55.26	Very Fine Silt	SRF
SSB 0504b	1.294	1.157	2.676	0.435	5.03	Clay	DMF
run 2	1.311	1.159	2.724	0.433	5.55	Clay	DMF
average	1.303	1.158	2.700	0.434	5.32	Clay	DMF
SSB 0504c	2.354	1.958	3.539	0.532	16.01	Clay	DMF
run 2	2.537	2.100	3.582	0.559	17.36	Clay	DMF
average	2.444	2.024	3.562	0.545	16.71	Clay	DMF
SSB 0504d	1.540	1.360	2.786	0.518	5.52	Clay	DMF
run 2	1.574	1.377	2.829	0.520	6.25	Clay	DMF
average	1.557	1.369	2.808	0.519	5.92	Clay	DMF
SSB 0504e	1.399	1.279	2.598	0.486	3.92	Clay	DMF
run 2	1.456	1.310	2.680	0.493	5.11	Clay	DMF
average	1.427	1.294	2.640	0.489	4.52	Clay	DMF
SSB 0505a	2.531	2.498	3.066	0.660	8.75	Clay	DMF
run 2	2.548	2.520	3.073	0.662	8.83	Clay	DMF
average	2.539	2.509	3.070	0.661	8.79	Clay	DMF
SSB 0505b	3.536	3.172	3.797	0.666	22.73	Clay	DMF
run 2	3.695	3.463	3.730	0.685	22.53	Clay	DMF
average	3.615	3.315	3.764	0.676	22.63	Clay	DMF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
SYB 0502	3.208	2.451	3.157	0.936	21.98	Clay	DMF
run 2	3.174	2.455	3.093	0.940	20.93	Clay	DMF
average	3.191	2.453	3.125	0.938	21.46	Clay	DMF
SYB 0503a	17.450	22.710	3.823	2.491	82.58	Medium Silt	DMF
run 2	16.790	21.720	3.754	2.469	77.46	Medium Silt	DMF
average	17.110	22.210	3.798	2.480	80.08	Medium Silt	DMF
SYB 0503b	13.010	15.130	3.699	2.079	64.64	Fine Silt	BFSF
run 2	12.850	14.880	3.649	2.098	62.97	Fine Silt	BFSF
average	12.930	15.010	3.674	2.089	63.76	Fine Silt	BFSF
SYB 0503c	24.130	31.510	3.831	3.592	109.40	Medium Silt	BFSF
run 2	22.900	29.780	3.761	3.493	102.50	Medium Silt	BFSF
average	23.510	30.630	3.797	3.541	106.00	Medium Silt	BFSF
SYB 0504	19.930	24.940	3.221	3.805	75.66	Medium Silt	BFSF
run 2	19.140	23.850	3.187	3.714	71.78	Medium Silt	BFSF
average	19.530	24.390	3.204	3.759	73.77	Medium Silt	BFSF
SYB 0505	24.290	27.380	3.749	4.055	117.30	Medium Silt	SRF
run 2	21.510	24.600	3.531	3.801	100.40	Medium Silt	SRF
average	22.850	25.950	3.645	3.923	108.70	Medium Silt	SRF
SYB 0506	5.396	5.983	3.323	1.043	23.35	Very Fine Silt	SRF
run 2	4.911	5.377	3.318	0.962	21.69	Very Fine Silt	SRF
average	5.148	5.674	3.323	1.000	22.49	Very Fine Silt	SRF
SYB 0507	9.327	12.120	3.181	1.842	31.69	Fine Silt	BFSF
run 2	9.046	11.800	3.218	1.722	31.57	Fine Silt	BFSF
average	9.185	11.960	3.200	1.778	31.63	Fine Silt	BFSF
SYB 0508	7.580	8.898	3.157	1.533	29.38	Very Fine Silt	BFSF
run 2	7.269	8.462	3.217	1.407	29.50	Very Fine Silt	BFSF
average	7.423	8.689	3.187	1.465	29.44	Very Fine Silt	BFSF
SYB 0509	14.190	17.650	2.987	3.131	45.68	Fine Silt	SRF
run 2	13.430	16.740	2.938	3.024	42.44	Fine Silt	SRF
average	13.800	17.180	2.963	3.076	43.96	Fine Silt	SRF
SYB 0510a	11.700	14.590	3.000	2.738	37.70	Fine Silt	SRF
run 2	11.310	14.040	3.001	2.637	36.70	Fine Silt	SRF
average	11.510	14.310	3.001	2.686	37.22	Fine Silt	SRF
SYB 0510b	13.600	20.910	4.202	1.586	62.89	Fine Silt	SRF
run 2	13.540	21.100	4.239	1.551	62.92	Fine Silt	SRF
average	13.580	21.010	4.220	1.568	62.90	Fine Silt	SRF
SYB 0510c	11.970	13.310	2.854	2.923	43.27	Fine Silt	SRF
run 2	11.130	12.390	2.841	2.734	40.24	Fine Silt	SRF
average	11.540	12.830	2.849	2.825	41.83	Fine Silt	SRF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
SYB 0511a	7.625	7.995	2.918	1.986	29.45	Very Fine Silt	SRF
run 2	7.123	7.566	2.855	1.918	25.95	Very Fine Silt	SRF
average	7.370	7.778	2.888	1.951	27.53	Very Fine Silt	SRF
SYB 0511b	6.564	6.214	2.880	1.706	27.81	Very Fine Silt	SRF
run 2	5.978	5.850	2.683	1.655	22.99	Very Fine Silt	SRF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
SCQ 1	3.294	5.095	3.979	0.303	12.23	Clay	DMF
run 2	3.281	5.077	3.968	0.303	12.12	Clay	DMF
average	3.288	5.086	3.973	0.303	12.17	Clay	DMF
SCQ 2	2.113	3.197	3.509	0.250	7.36	Clay	DMF
run 2	2.108	3.198	3.516	0.248	7.35	Clay	DMF
average	2.111	3.198	3.513	0.249	7.36	Clay	DMF
SCQ 3	2.612	3.875	3.975	0.252	10.36	Clay	DMF
run 2	2.604	3.869	3.991	0.249	10.35	Clay	DMF
average	2.608	3.872	3.983	0.251	10.36	Clay	DMF
SCQ 4	2.420	3.583	3.683	0.363	8.67	Clay	DMF
run 2	2.412	3.579	3.685	0.260	8.64	Clay	DMF
average	2.416	3.581	3.684	0.261	8.66	Clay	DMF
SCQ 5	2.401	3.681	3.546	0.281	8.34	Clay	BFSF
run 2	2.403	3.684	3.543	0.281	8.33	Clay	BFSF
average	2.402	3.682	3.545	0.281	8.33	Clay	BFSF
SCQ 6	2.390	2.123	3.195	0.614	12.25	Clay	BFSF
run 2	2.462	2.179	3.249	0.620	13.20	Clay	BFSF
average	2.425	2.151	3.222	0.617	12.73	Clay	BFSF
SCQ 7	11.720	17.860	3.631	1.533	43.20	Fine Silt	BFSF
run 2	11.670	17.770	3.629	1.533	43.14	Fine Silt	BFSF
average	11.700	17.820	3.630	1.533	43.17	Fine Silt	BFSF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
STT 01	5.138	4.896	4.122	0.857	35.49	Very Fine Silt	DMF
run 2	4.699	4.596	3.816	0.855	28.29	Very Fine Silt	DMF
average	4.914	4.738	3.971	0.856	31.58	Very Fine Silt	DMF
STT 02	12.720	14.710	3.966	2.154	68.21	Fine Silt	DMF
run 2	11.330	13.230	3.776	2.060	54.69	Fine Silt	DMF
average	12.010	13.940	3.875	2.106	60.97	Fine Silt	DMF
STT 03	10.890	12.370	4.351	1.598	67.01	Fine Silt	DMF
run 2	9.804	11.150	4.163	1.541	55.74	Fine Silt	DMF
average	10.330	11.720	4.261	1.569	61.08	Fine Silt	DMF
STT 04	9.717	10.190	3.836	1.856	55.63	Fine Silt	DMF
run 2	8.635	9.274	3.612	1.785	42.39	Fine Silt	DMF
average	9.160	9.704	3.728	1.820	48.45	Fine Silt	DMF
STT 05	11.150	11.240	3.239	2.671	51.33	Fine Silt	DMF
run 2	10.190	10.570	3.035	2.610	41.11	Fine Silt	DMF
average	10.660	10.890	3.139	2.640	45.71	Fine Silt	DMF
STT 06	10.080	10.040	2.947	2.741	40.83	Fine Silt	DMF
run 2	9.651	9.754	2.845	2.718	36.91	Fine Silt	DMF
average	9.861	9.890	2.897	2.729	38.30	Fine Silt	DMF
STT 07	9.683	9.977	3.192	2.190	42.60	Fine Silt	BFSF
run 2	9.196	9.525	3.102	2.158	38.80	Fine Silt	BFSF
average	9.436	9.741	3.148	2.173	40.64	Fine Silt	BFSF
STT 08	12.450	12.790	2.755	3.627	44.03	Fine Silt	BFSF
run 2	11.700	12.260	2.631	3.564	38.52	Fine Silt	BFSF
average	12.070	12.520	2.695	3.595	41.13	Fine Silt	BFSF
STT 09	12.990	16.370	2.993	2.802	42.31	Fine Silt	BFSF
run 2	12.310	15.620	2.939	2.703	39.04	Fine Silt	BFSF
average	12.640	15.990	2.967	2.751	40.59	Fine Silt	BFSF
STT 10	13.570	14.890	2.734	3.910	44.03	Fine Silt	BFSF
run 2	12.740	14.170	2.649	3.805	39.46	Fine Silt	BFSF
average	13.150	14.520	2.693	3.857	41.71	Fine Silt	BFSF
STT 11	14.230	14.710	2.740	4.319	49.67	Fine Silt	BFSF
run 2	13.340	14.060	2.633	4.224	43.28	Fine Silt	BFSF
average	13.780	14.370	2.688	4.271	46.33	Fine Silt	BFSF
STT 12	16.840	17.480	2.768	4.903	60.01	Medium Silt	BFSF
run 2	15.000	15.850	2.640	4.644	49.10	Medium Silt	BFSF
average	15.890	16.630	2.709	4.767	54.28	Medium Silt	BFSF
STT 13	11.810	12.680	2.598	3.489	38.64	Fine Silt	BFSF
run 2	11.240	12.080	2.563	3.395	35.94	Fine Silt	BFSF
average	11.520	12.370	2.581	3.441	37.31	Fine Silt	BFSF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
STT 14	6.948	8.014	3.129	1.413	27.00	Very Fine Silt	BFSF
run 2	6.807	7.853	3.156	1.363	26.83	Very Fine Silt	BFSF
average	6.877	7.934	3.143	1.388	26.92	Very Fine Silt	BFSF
STT 15	5.846	6.175	3.267	1.183	26.74	Very Fine Silt	BFSF
run 2	5.734	6.028	3.298	1.154	26.64	Very Fine Silt	BFSF
average	5.789	6.101	3.283	1.169	26.69	Very Fine Silt	BFSF
STT 16	6.520	7.511	3.332	1.203	28.16	Very Fine Silt	BFSF
run 2	6.480	7.519	3.383	1.166	28.49	Very Fine Silt	BFSF
average	6.500	7.515	3.357	1.185	28.33	Very Fine Silt	BFSF
STT 17	7.820	10.870	3.523	1.194	31.23	Fine Silt	BFSF
run 2	7.801	10.920	3.543	1.178	31.31	Fine Silt	BFSF
average	7.810	10.890	3.533	1.185	31.27	Fine Silt	BFSF
STT 18	6.455	6.870	3.172	1.349	27.72	Very Fine Silt	BFSF
run 2	6.347	6.734	3.231	1.296	27.96	Very Fine Silt	BFSF
average	6.401	6.802	3.202	1.322	27.84	Very Fine Silt	BFSF
STT 19	4.598	4.433	2.788	1.266	18.83	Very Fine Silt	BFSF
run 2	4.523	4.334	2.862	1.227	19.24	Very Fine Silt	BFSF
average	4.560	4.384	2.825	1.246	19.03	Very Fine Silt	BFSF
STT 20	7.204	7.775	3.132	1.615	29.03	Very Fine Silt	BFSF
run 2	7.118	7.643	3.144	1.602	28.87	Very Fine Silt	BFSF
average	7.161	7.709	3.138	1.608	28.96	Very Fine Silt	BFSF
STT 21	8.215	8.502	2.874	1.968	33.04	Fine Silt	BFSF
run 2	8.061	8.306	2.862	1.949	32.36	Fine Silt	BFSF
average	8.138	8.404	2.868	1.958	32.70	Fine Silt	BFSF
STT 22	9.332	9.752	3.049	2.176	39.51	Fine Silt	BFSF
run 2	9.159	9.551	3.035	2.161	38.72	Fine Silt	BFSF
average	9.245	9.651	3.042	2.168	39.12	Fine Silt	BFSF
STT 23	9.994	10.700	3.004	2.311	40.66	Fine Silt	BFSF
run 2	9.607	10.200	2.974	2.277	38.89	Fine Silt	BFSF
average	9.799	10.440	2.990	2.294	39.73	Fine Silt	BFSF
STT 24	11.290	12.080	2.958	2.523	45.46	Fine Silt	BFSF
run 2	10.790	11.500	2.902	2.481	42.77	Fine Silt	BFSF
average	11.040	11.780	2.930	2.501	44.08	Fine Silt	BFSF
STT 25	44.510	89.970	4.744	2.853	152.00	Coarse Silt	BFSF
run 2	46.260	90.150	4.623	3.053	152.70	Coarse Silt	BFSF
average	45.380	90.060	4.684	2.946	152.40	Coarse Silt	BFSF
STT 26	9.041	8.349	5.064	1.087	75.59	Fine Silt	BFSF
run 2	9.074	8.634	5.115	1.059	74.71	Fine Silt	BFSF
average	9.057	8.490	5.089	1.073	75.13	Fine Silt	BFSF

Appendix 3: Grain Size Data for Etadunna Formation, continued

Sample ID	Mean	Median	S.D.	d10	d90	Classification	Facies
STT 27	12.870	10.430	5.778	1.407	131.40	Fine Silt	BFSF
run 2	12.950	10.760	5.928	1.349	131.10	Fine Silt	BFSF
average	12.910	10.590	5.853	1.378	131.30	Fine Silt	BFSF
STT 28	5.836	5.120	3.777	1.234	43.55	Very Fine Silt	BFSF
run 2	5.780	4.993	3.890	1.193	45.26	Very Fine Silt	BFSF
average	5.808	5.057	3.834	1.213	44.41	Very Fine Silt	BFSF

Appendix 4: Fossil avifauna with locality and lithologic data from the Etadunna Formation.

Appendix 4: Avifauna from the Minkina LF (A)

Spec. #	Element	Order	Family
JEH006	Humerus (?distal, right)	Galliformes	Phasianidae
22958	Femur (distal, right)	Galliformes	Phasianidae
21914	Tarsometatarsus (distal, right)	Galliformes	Phasianidae
YBQ 02-09	Tibiotarsus (distal, right)	Procellariiformes	Procellariidae
JEH005	Scapula (proximal, right)	Pelecaniformes	Phalacrocoracidae
P27995	?	Ciconiiformes	Palaelodidae
P41291	Coracoid (left)	Ciconiiformes	Palaelodidae
JEH011A	Ulna (distal, left)	Ciconiiformes	Palaelodidae
JEH011B	?Carpometacarpus (distal)	Ciconiiformes	Palaelodidae
JEH009A	Tibiotarsus (distal, right)	Ciconiiformes	Palaelodidae
21890	Tibiotarsus (distal, right)	Ciconiiformes	Palaelodidae
22932	Tibiotarsus (distal, right)	Ciconiiformes	Palaelodidae
22037	Tibiotarsus (distal, left)	Ciconiiformes	Palaelodidae
JEH011C	Tarsometatarsus (left)	Ciconiiformes	Palaelodidae
P41249	Tarsometatarsus (left)	Ciconiiformes	Palaelodidae
P22709	Tarsometatarsus (proximal)	Ciconiiformes	Palaelodidae
P41313	Tarsometatarsus (Juv., proximal, right)	Ciconiiformes	Palaelodidae
P36678	Tarsometatarsus (proximal, distal frag)	Ciconiiformes	Palaelodidae
P41315	Tarsometatarsus (distal, right)	Ciconiiformes	Palaelodidae
P33762	Tarsometatarsus (distal, left)	Ciconiiformes	Palaelodidae
P41260	Wing phalanx II (right)	Ciconiiformes	Phoenicopteridae
P33791	?	Ciconiiformes	Phoenicopteridae
P41259	Scapula (right)	Ciconiiformes	Phoenicopteridae
P41314	Scapula (left)	Ciconiiformes	Phoenicopteridae
P41306	Coracoid (left)	Ciconiiformes	Phoenicopteridae
P41306	Coracoid (left)	Ciconiiformes	Phoenicopteridae
P41252	Humerus (distal, left)	Ciconiiformes	Phoenicopteridae
P33793	Radius	Ciconiiformes	Phoenicopteridae
P22708	Carpometacarpus (right)	Ciconiiformes	Phoenicopteridae
P41254	Carpometacarpus	Ciconiiformes	Phoenicopteridae

Appendix 4: Avifauna from the Minkina LF (A), continued

Spec. #	Genus	Species	Length	Width	Art. Sur.
JEH006	?	?	19.4	N/A	15.33
22958	?	?	N/A	N/A	8.18
21914	?	?	18.44	3.98	9.36
YBQ 02-09	?*Diomedea*	?	186.34	9.36	20.72
JEH005	*Phalacrocorax*	?	35.54	4.15	15.99
P27995	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P41291	*Paleolodus*	*Paleolodus* sp.	N/A	N/A	N/A
JEH011A	*Palaelodus*	?	65.05	8.76	13.83
JEH011B	*Palaelodus*	?	42.71	4.51	9.68
JEH009A	*Palaelodus*	?	43.33	7.42	14.2
21890	*Palaelodus*	?	57.37	7.73	15.85
22932	?*Palaelodus*	?	32.4	7.17	N/A
22037	*Palaelodus*	?	60.12	7.25	13.45
JEH011C	*Palaelodus*	?	133.55	N/A	16.38
P41249	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P22709	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P41313	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P36678	*Palaelodus*	cf. Palaelodus pledgei	N/A	N/A	N/A
P41315	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P33762	*Palaelodus*	*Palaelodus* cf. *wilsoni*	N/A	N/A	N/A
P41260	*Phoenicopterus*	*Phoenicopterus eyrensis*	N/A	N/A	N/A
P33791	*Phoenicopterus*	?	N/A	N/A	N/A
P41259	*Phoenicopterus*	?	N/A	N/A	N/A
P41314	*Phoenicopterus*	?	N/A	N/A	N/A
P41306	*Phoenicopterus*	?	N/A	N/A	N/A
P41306	*Phoenicopterus*	?	N/A	N/A	N/A
P41252	*Phoenicopterus*	?	N/A	N/A	N/A
P33793	*Phoenicopterus*	?	N/A	N/A	N/A
P22708	*Phoenicopterus*	?	N/A	N/A	N/A
P41254	*Phoenicopterus*	?	N/A	N/A	N/A

Appendix 4: Avifauna from the Minkina LF (A), continued

Spec. #	Locality Name	Locality #
JEH006	SIAM	RV-7232
22958	Young Buck's Quarry	RV-9002
21914	Mother Lode	RV-8504
YBQ 02-09	Young Buck's Quarry	RV-9002
JEH005	Mother Lode	RV-8504
P27995	Neville's Nirvana	?
P41291	Neville's Nirvana	?
JEH011A	?	?
JEH011B	?	?
JEH009A	Jim's Shell Hole	JAC 03-22
21890	Mother Lode	RV-8504
22932	Young Buck's Quarry	RV-9002
22037	Turtle Quarry	RV-8504
JEH011C	Young Buck's Quarry	RV-9002
P41249	Young Bucks Quarry	RV-9002
P22709	Neville's Nirvana	?
P41313	Young Bucks Quarry	RV-9002
P36678	Young Bucks Quarry	RV-9002
P41315	Young Bucks Quarry	RV-9002
P33762	Young Bucks Quarry	RV-9002
P41260	Young Bucks Quarry	RV-9002
P33791	Mother Lode	RV-8504
P41259	Mother Lode	RV-8504
P41314	Young Bucks Quarry	RV-9002
P41306	Neville's Nirvana	?
P41306	Neville's Nirvana	?
P41252	Neville's Nirvana	?
P33793	Young Bucks Quarry	RV-9002
P22708	Neville's Nirvana	?
P41254	Young Bucks Quarry	RV-9002

Appendix 4: Avifauna from the Minkina LF (A)

Spec. #	**Element**	**Order**	**Family**
22306	Ulna (distal, left)	Ciconiiformes	Phoenicopteridae
P41292	Fibula (right)	Ciconiiformes	Phoenicopteridae
YBQ 02-07	Tarsometarsus (shaft)	Ciconiiformes	Phoenicopteridae
VP0703	Tarsometatarsus (proximal, right)	Gruiformes	?Gruidae
P22707	Carpometacarpus (tiny)	Ralliformes	Rallidae
JEH009B	Tarsometarsus (distal, right)	Charadriiformes	Recurvirostridae
P41309	?	?Charadriiformes	?

Appendix 4: Avifauna from the Minkina LF (A), continued

Spec. #	Genus	Species	Length	Width	Art. Sur.
22306	*Phoenicopterus*	?	53.7	6.04	10.84
P41292	*Phoenicopterus*	?	N/A	N/A	N/A
YBQ 02-07	*Phoenicopterus*	?	127.64	5.36	N/A
VP0703	?	?	25.95	4.97	11.42
P22707	Rail	?	N/A	N/A	N/A
JEH009B	*Recurvirostra*	?	4.1.10	3.72	8.78
P41309	?	?	N/A	N/A	N/A

Appendix 4: Avifauna from the Minkina LF (A), continued

Spec. #	Locality Name	Locality #
22306	Young Buck's Quarry	RV-9002
P41292	Neville's Nirvana	?
YBQ 02-07	Young Buck's Quarry	RV-9002
VP0703	Jim's Shell Hole	JAC 03-22
P22707	Neville's Nirvana	?
JEH009B	Jim's Shell Hole	JAC 03-22
P41309	Neville's Nirvana	?

Appendix 4: Avifauna from the Ditjimanka and Ngapakaldi LF (B,C)

Spec. #	Element	Order	Family
JEH007B	Scapula (left)	Anseriformes	Anatidae
JEH007A	Coracoid (proximal, right)	Anseriformes	Anatidae
16082	Tibiotarsus (distal, right)	Anseriformes	Anatidae
P42007	?	Ciconiiformes	Palaelodidae
VP0360	Tarsometatarsus (distal)	Ciconiiformes	?Palaelodidae
P41323	Radius (right)	Ciconiiformes	Phoenicopteridae
JEH010C	Carpometacarpus (left)	Ciconiiformes	Phoenicopteridae
22712	Femur (distal, right)	Ciconiiformes	?Phoenicopteridae
22711	Humerus (distal, right)	Ralliformes	Rallidade
22714	Humerus (distal, right)	Ralliformes	Rallidade
JEH007C	Carpometacarpus (proximal, left)	Charadriiformes	?
22713	Radius (distal, right)	Falconiformes	Pandionidae
P27975	Tarsometatarsus (distal)	Falconiformes	Accipitridae
16095B	Coracoid (distal, right)	Psittaciformes	Cacatuidae
16090	Radius (distal, left)	Trogoniformes	Trogonidae
JEH007	Tarsometatarsus (proximal, right)	Passeriformes	Corvidae
16082	TMT, no specimen	Passeriformes	?
P36786	Pedal phalanx	Wading bird	?

Appendix 4: Avifauna from the Ditjimanka and Ngapakaldi LF (B,C), continued

Spec. #	Genus	Species	Length	Width	Art. Sur.
JEH007B	*Dendrocygna*	?	16.19	N/A	9.64
JEH007A	*Dendrocygna*	?	18.37	3.11	8.46
16082	?	?	N/A	N/A	7.46
P42007	?*Paleolodus*	?	N/A	N/A	N/A
VP0360	?	?	22.84	6.34	N/A
P41323	*Phoenicopterus*	?	N/A	N/A	N/A
JEH010C	*Phoenicopterus*	?	46.54	6.43	16.35
22712	?	?	54.76	7.33	18.02
22711	?	?	17.13	2.6	5.91
22714	?	?	N/A	N/A	5.65
JEH007C	?	?	11.15	1.76	4.44
22713	?	?	40.94	3.86	9.82
P27975	?	?	N/A	N/A	N/A
16095B	*Cacatua*	?	10.19	N/A	4.87
16090	?	?	11.71	1.31	2.78
JEH007	?	?	8.58	1.71	2.8
16082	?	?	N/A	N/A	N/A
P36786	?	?	N/A	N/A	N/A

Appendix 4: Avifauna from the Ditjimanka and Ngapakaldi LF (B,C), continued

Spec. #	Locality Name	Locality #
JEH007B	Steve's Site/Pledge's Pride	RV-8447
JEH007A	Steve's Site/Pledge's Pride	RV-8447
16082	Tedford Locality	RV-7230
P42007	Tedford Basin	RV-7230
VP0360	Flamingo Cliffs	V711171
P41323	Tedford East	RV-7230
JEH010C	Jeanne's Rooery	RV-8451
22712	Tedford Locality	RV-7230/V-5375
22711	Tedford Locality	RV-7230, V-5375
22714	Janice's Site	RV-8484
JEH007C	Steve's Site/Pledge's Pride	RV-8447
22713	Janice's Site	RV-8448
P27975	Steve's Site	RV-8447
16095B	Tedford Locality	RV-7230
16090	Tedford Locality	RV-7230
JEH007	Steve's Site/Pledge's Pride	RV-8447
16082	Tedford Locality	RV-7230
P36786	SIAM Site	RV-7232

Appendix 4: Avifauna from the Ngama LF (D)

Spec. #	Element	Order	Family
P23977	Tarsometatarsus	Casuariiformes	Casuariidae
P41876	Pedal phalanx	?Ratite	?
P36761	Coracoid	Ciconiiformes	Ciconiidae
P41294	Scapula (2, proximal)	Ciconiiformes	Palaelodidae
P42009	Ulna (right)	Ciconiiformes	Palaelodidae
P41298	Ulna (distal)	Ciconiiformes	Palaelodidae
P41296	Tibia (proximal, right)	Ciconiiformes	Palaelodidae
P27973	Tibia (distal, left)	Ciconiiformes	Palaelodidae
P41297	?	Ciconiiformes	Phoenicopteridae
P27838	Vertebra	Ciconiiformes	Phoenicopteridae
P41465	Scapula (right)	Ciconiiformes	Phoenicopteridae
P41464	Scapula (right)	Ciconiiformes	Phoenicopteridae
P41875	Humerus	Ciconiiformes	Phoenicopteridae
P30168	Humerus (partial, proximal, left)	Ciconiiformes	Phoenicopteridae
P41303	Radius (distal, right)	Ciconiiformes	Phoenicopteridae
P24558	Manus phalanx II.1 (right)	Ciconiiformes	Phoenicopteridae
P24557	Tibiotarsus (right)	Ciconiiformes	Phoenicopteridae
P39231	Tibiotarsus, tarsometatarsus (associated)	Ciconiiformes	Phoenicopteridae
P27822	Tarsometatarsus (Juv., proximal, right)	Ciconiiformes	Phoenicopteridae
P27826	Humerus (distal, left)	Ralliformes	Rallidae
P27837	Carpometacarpus (proximal, left)	Charadriiformes	?

Appendix 4: Avifauna from the Ngama LF (D)

Spec. #	Genus	Species	Locality Name
P23977	*Eumuarius*	*Eumuarius guljaruba*	Mammalon Hill
P41876	?	?	Mammalon Hill
P36761		?	Mammalon Hill
P41294	*Palaelodus*	?*Palaelodus mags pledgei*	Mammalon Hill
P42009	*Palaelodus*	*Palaelodus* ?*pledgei*	Mammalon Hill
P41298	*Palaelodus*	?*Palaelodus*	Mammalon Hill
P41296	*Palaelodus*	?	Mammalon Hill
P27973	*Palaelodus*	*Palaelodus wilsoni*	Mammalon Hill
P41297	*Phoenicopterus*	?	Mammalon Hill
P27838	?*Phoenicopterus*	?	Mammalon Hill
P41465	*Phoenicopterus*	?	Mammalon Hill
P41464	*Phoenicopterus*	?	Mammalon Hill
P41875	*Phoenicopterus*	?	Mammalon Hill
P30168	*Phoenicopterus*	?	Mammalon Hill
P41303	*Phoenicopterus*	?	Mammalon Hill
P24558	*Phoenicopterus*	?	Mammalon Hill
P24557	*Phoenicopterus*	?	Mammalon Hill
P39231	*Phoenicopterus*	?	Mammalon Hill
P27822	*Phoenicopterus*	?	Mammalon Hill
P27826	?	?	Mammalon Hill
P27837	?	?	Mammalon Hill

Appendix 4: Avifauna from the Treasure/Lungfish LF (E)

Spec. #	**Element**	**Order**	**Family**
SAR 302A	Coracoid (distal, left)	Anseriformes	Anatidae
22046	Tarsometatarsus (distal, right)	Ciconiiformes	Palaelodidae
P41319	Humerus (distal, right)	Ciconiiformes	Palaelodidae
P36783	Tarsometatarsus (proximal, left)	Ciconiiformes	Phoenicopteridae
21893	Tibiotarsus (distal, left)	Ciconiiformes	Threskiornithidae

Appendix 4: Avifauna from the Treasure/Lungfish LF (E), continued

Spec. #	**Genus**	**Species**	**Length**	**Width**	**Art. Sur.**
SAR 302A	?	?	14.68	N/A	8.1
22046	*Palaelodus*	?	26.95	10.61	N/A
P41319	*Palaelodus*	*Palaelodus wilsoni*	N/A	N/A	N/A
P36783	*Phoenicopterus*	?	N/A	N/A	N/A
21893	*Eudocimus*	?	30.88	3.81	8.34

Appendix 4: Avifauna from the Treasure/Lungfish LF (E), continued

Spec. #	Locality Name	Locality #
SAR 302A	Lungfish Locality	RV-7233/V-5766
22046	Lungfish Locality	RV-7233
P41319	Lungfish Locality	RV7233
P36783	Lungfish North Quarry	RV7233
21893	Lungfish Locality	RV-7233