

THE KIRTLANDIAN LAND-VERTEBRATE “AGE”—FAUNAL COMPOSITION, TEMPORAL POSITION AND BIOSTRATIGRAPHIC CORRELATION IN THE NONMARINE UPPER CRETACEOUS OF WESTERN NORTH AMERICA

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Abstract—The Kirtlandian land-vertebrate “age” (LVA) is equivalent to 2.2 million years of Campanian time and fills a long-standing biochronologic gap between the Judithian and Edmontonian LVAs. The Kirtlandian is characterized by the vertebrate fossil assemblages of the Fruitland and Kirtland formations, San Juan Basin, New Mexico. *Pentaceratops sternbergii*, a ceratopsid taxon, is the principal index fossil. Other index fossils are the hadrosaur taxa *Parasaurolophus cyrtocristatus* and *Kritosaurus navajovius*. Unique taxa include: *Melivius chauliodous*, *Denazinemys ornata*, *Boremys grandis*, *Adocus bossi*, *A. kirtlandius*, *Neurankylus baueri*, *Thescelus hemispherica*, *Aspideretes ovatus*, “*Plastomenus*” *robustus*, *Denazinosuchus kirtlandicus*, *Saurornitholestes robustus*, *Anasazisaurus horneri*, *Kritosaurus navajovius*, *Naashoibitosaurus ostromi*, *Parasaurolophus cyrtocristatus*, *P. tubicen*, *Nodocephalosaurus kirtlandensis*, *Kritosaurus navajovius*, *Prenocephale goodwini* and *Pentaceratops sternbergii*. The Kirtlandian LVA is defined as the time between the first appearance of *Pentaceratops sternbergii* (= end of the Judithian) and the first appearance of *Edmontosaurus regalis* (= beginning of the Edmontonian).

Principal correlatives of the characteristic Kirtlandian vertebrate assemblage are the vertebrate faunas of the lower part of the Bearpaw Formation of Montana, USA and Alberta, Canada; Williams Fork Formation, northwestern Colorado; upper part of the Kaiparowits Formation, south-central Utah; Fort Crittenden Formation, southeastern Arizona; Ringbone Formation, southwestern New Mexico; Corral de Enmedio and Packard formations of the Cabullona Group, Sonora, Mexico; El Gallo Formation, Baja California del Norte, Mexico; and possibly the lower part of the Cerro del Pueblo Formation, Coahuila, Mexico. The upper shale member of the Aguja Formation, Big Bend region, Texas, may be correlative to part of the Kirtlandian based on recently published radioisotopic dates.

Recognition of the Kirtlandian undermines the concept of two paleogeographically distinct dinosaur paleocommunities in the Western Interior during the late Campanian. Thus, more precise vertebrate biochronology indicates that vertebrate assemblages previously considered characteristic of northern and southern provinces are not coeval; the differences are thus temporal, not biogeographic origin.

INTRODUCTION

Russell (1975), in a classic paper, introduced, defined and applied to the Upper Cretaceous of North America five “stages” (Paluxian, Aquilan, Judithian, Edmontonian, and Lancian) based largely on fossil mammal assemblages (except for the Edmontonian, discussed below). Russell (1975) identified gaps between the Paluxian and Aquilan, the Aquilan and Judithian, and the Judithian and Edmontonian, with the first gap having the greatest magnitude.

Sullivan and Lucas (2003a) recently named the youngest of these three gaps the Kirtlandian land-vertebrate “age” (LVA). The Kirtlandian LVA is the interval of time between the Judithian and Edmontonian LVAs. It fills a gap in the North American Cretaceous LVA succession that spans some 2.2 million years, from 75 to 72.8 Ma (middle late Campanian), and is characterized by a vertebrate fauna based on the vertebrate fossil assemblages of the upper Fruitland Formation and the Kirtland Formation in the San Juan Basin, New Mexico (Fig. 1). Here, we further document and develop the concept of the Kirtlandian LVA. We also apply this concept to resolve problems of Late Cretaceous correlation and paleobiogeography in the Western Interior.

INSTITUTIONAL ABBREVIATIONS

AMNH = American Museum of Natural History, New York, USA; BYU = Brigham Young University, Provo, Utah, USA; CMN = Canadian Museum of Nature, Ottawa, CANADA (formerly NMC = National Museum of Canada); FMNH = Field Museum of Natural History, Chicago, Illinois, USA; KUVN = Natural History Museum, University of Kansas, Lawrence, Kansas, USA; NMMNH = New Mexico Museum of Natu-

ral History and Science, Albuquerque, New Mexico, USA; PMU = University of Uppsala, Museum of Evolution (Paleontologiska Museet), Uppsala, SWEDEN; SDNMH = San Diego Natural History Museum, San Diego, California, USA; SMP = The State Museum of Pennsylvania, Harrisburg, Pennsylvania, USA; USNM = Natural History Museum, United States National Museum, Smithsonian Institution, Washington, D.C., USA.

VERTEBRATE BIOCHRONOLOGY

Russell’s (1975) Cretaceous stages, which were (in part) introduced and conceived of in an earlier work (Russell, 1964), were partly based on a concept that grew out of the North American provincial “ages” established earlier by Wood et al. (1941) for the Tertiary terrestrial sequence of fossil mammal faunas (also see Tedford, 1970). These were not intended by Russell (1964, 1975) to be “stages” in any formal sense, but instead each was established as a “provincial stage term to include time and strata represented by the faunas.” They are thus biochronological entities, based mostly on a succession of mammalian taxa. In other words, these “stages” are land-vertebrate “ages” (or faunachrons) and thus are biochronological units based on vertebrate fossils (Lucas, 1992b). Such “ages” have been widely used by vertebrate biostratigraphers and paleontologists for intracontinental correlation (e.g., Tedford, 1970; Woodburne, 1987). Faunachrons, or vertebrate “ages,” are temporal units that are defined by biological criteria (biochronological units): these include index fossils, first appearance, last appearance and characteristic fossils (Tedford, 1970). They lack stratigraphic characterization and are not biostratigraphic units as they are not explicitly defined by, or tied to, any stratum or sequence of rock (Fig. 1).

Both Fox (1978) and Lillegraven and McKenna (1986) reviewed

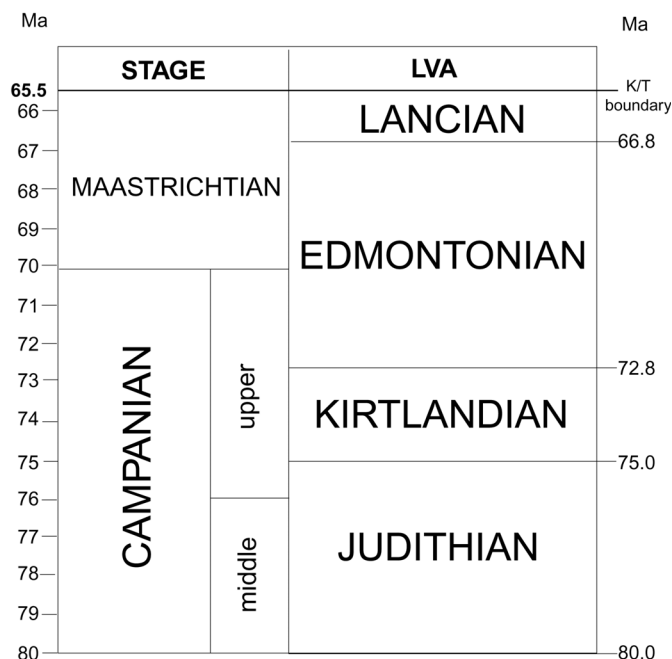


FIGURE 1. North American Late Cretaceous land-vertebrate “ages” (modified from Russell 1975 [only relevant ages shown]; updated with data from Eberth et al., 2001; Lerbekmo and Braman, 2002; and Sullivan and Lucas, 2003a).

Russell’s (1964, 1975) Upper Cretaceous stages (ages) and re-characterized those that were defined by mammals (Aquilan, Judithian, Edmontonian and Lancian). In particular, Lillegraven and McKenna (1986) redefined the “age” terms for the Aquilan, Judithian and Lancian using a combination of criteria including: 1) principal mammalian faunal correlative; 2) first appearance; 3) last appearance; and 4) unique occurrences. They also recognized that the Edmontonian “age” could not be characterized on the basis of mammalian taxa (and this is still the case: Cifelli et al., 2004); but, based on dinosaur taxa, it represents a “discrete interval of geologic time.”

Explicit in the work of Lillegraven and McKenna (1986) and others who want to view the North American Late Cretaceous vertebrate ages as only mammal based is the idea that the Late Cretaceous mammal fossil record can provide as robust a biostratigraphy and biochronology as does the Cenozoic record. This is clearly not the case at present. Indeed, a comparison of Cifelli et al. (2004) to Lillegraven and McKenna (1986) reveals just how little progress has been made in Late Cretaceous mammalian biochronology during the last two decades. This is largely due to a real lack of knowledge of this record, which has been little collected in many stratigraphic units. Furthermore, a lack of extensive and stable taxonomy, as well as the evident endemism of most Late Cretaceous mammal species hinders their use in biostratigraphy. The current inadequacy of Late Cretaceous mammalian biostratigraphy and biochronology is best illustrated by the Edmontonian LVA, which is at least 6 million years long but can neither be defined nor subdivided using fossil mammals (Cifelli et al., 2004).

Faced with this inadequacy, we advocate developing a Late Cretaceous biochronology based not just on mammals, but one that includes non-mammalian vertebrates (especially dinosaurs and turtles) that have relatively limited temporal ranges and relatively broad geographic ranges. We stress here that dinosaurs (including some ichnite taxa) and many other non-mammalian vertebrates have great potential for correlation (Russell, 1964, 1975; Lucas, 1991, 1997, 1998) that has been ignored by those who only use mammals for biostratigraphy.

LITHOSTRATIGRAPHY

Development of the lithostratigraphy of the Fruitland and Kirtland formations in the San Juan Basin, New Mexico and Colorado (Fig. 2) be-

gan with Bauer (1916), and has been reviewed by Hunt and Lucas (1992, 2003). Bauer (1916) named the Fruitland and Kirtland formations, and he divided the Kirtland Formation into three units: lower shale, Farmington Sandstone, and upper shale. He defined the overlying Ojo Alamo Sandstone (now Formation) to consist of a lower conglomerate, middle shale and upper conglomerate. Baltz et al. (1966) redefined the Ojo Alamo Formation, removing the lower conglomerate and middle shale from it and naming them the Naashoibito Member of the Kirtland Formation. Hunt and Lucas (1992) formalized all member-level terminology of the Kirtland Formation, recognizing the (in ascending order) Bisti, Hunter Wash, Farmington, De-na-zin and Naashoibito members. However, following Fassett (various papers) and Lucas and Sullivan (2000a), we (Sullivan and Lucas, 2003a; Sullivan et al., 2005a,b) recently placed the Naashoibito Member back in the Ojo Alamo Formation (Fig. 2).

The Fruitland Formation is, on average, 91–107 m thick and is a succession of coal-bearing clastic strata, in part, laterally equivalent to, and in part, overlying the Pictured Cliffs Sandstone, a regressive marine shoreline deposit (Fassett and Hinds 1971). It consists of two members, a lower coal-bearing Ne-nah-ne-zad Member and an upper Fossil Forest Member (Hunt and Lucas, 2003). The boundary between the Fruitland and the overlying Kirtland Formation is gradational and conformable, and it is placed at the base of a distinctive, ferruginous sandstone, the Bisti Bed at the base of the Kirtland Formation.

The Kirtland Formation is as much as 594 m thick and is a complex succession of sandstone, siltstone, mudstone, coal and shale (Fassett and Hinds, 1971). The top of the Kirtland Formation is marked by a distinct unconformity, overlain locally by the lower conglomerate of the Ojo Alamo Formation and basin-wide by sandstone/conglomerate at the Ojo Alamo base. We recently reassessed the members of the Fruitland and Kirtland formations (Sullivan and Lucas, 2003a) and recognize only three members: Hunter Wash, Farmington, and De-na-zin, and consider the Bisti Member to be a bed of the Hunter Wash Member (Fig. 2).

BIOSTRATIGRAPHY

Two vertebrate faunas, the Hunter Wash local fauna and the Willow Wash local fauna, collectively characterize the Kirtlandian LVA (Fig. 3). Clemens (1973, p. 165) defined the Hunter Wash local fauna for the fossil vertebrates “obtained from the upper 40 feet of the Fruitland Formation and the lower 55 feet of the lower shale of the Kirtland Shale in Hunter Wash.” This stratigraphic interval encompasses the vertebrate-bearing strata exposed in the Bisti region of the Bisti/De-na-zin Wilderness, and is coeval with the Fossil Forest section and much of the rock sequence exposed in the Ah-shi-sle-pah Wash region (Fig. 3). Clemens (1973) reviewed some of the taxa from this interval, which include vertebrate fossils reported by Gilmore (1916, 1919, 1935), and we review the taxonomic status of these taxa below.

Williamson and Sullivan (1998) named the Willow Wash local fauna for fossil vertebrates from the De-na-zin Member of the Kirtland Formation. Many of the vertebrate taxa of the Willow Wash local fauna were formerly considered part of the Alamo Wash local fauna (Lehman, 1981) of the Naashoibito Member (Ojo Alamo Formation) but were subsequently shown to originate in the De-na-zin Member of the Kirtland Formation (Williamson, 2000; Williamson and Sullivan, 1998; Sullivan et al., 2005a,b).

Comparison of key genera from the Hunter Wash local fauna and the Willow Wash local fauna shows striking similarity (Table 1). At the species level, the two local faunas share several taxa. These include: *Myledaphus bipartitus* Cope, *Melivius chauliodous* (Hall and Wolberg), *Denazinemys nodosa* (Gilmore), *Neurankylus baueri* Gilmore, *Thescelus hemispherica* Gilmore, *Basilemys nobilis* Hay, “*Plastomenus*” *robustus* Gilmore, *Brachychampsia montana* Gilmore, *Saurornitholestes cf. S. robustus* Sullivan, and *Pentaceratops sternbergii* Osborn. Dinosaur taxa that occur in the Willow Wash local fauna, and that may occur in the older Hunter Wash local fauna (based on incomplete or fragmentary evidence), include *Kritosaurus navajovius* Brown, *Nodocephalosaurus kirtlandensis* Sullivan and *Prenocephale goodwini* (Williamson and Carr). Despite re-

Bauer (1916)	Baltz et al. (1966)	Hunt & Lucas (1992, 2003)	this paper
<div>Ojo Alamo Sandstone</div> <div>upper conglomerate</div> <div></div> <div>middle shale</div> <div>lower cgl.</div>	<div>Ojo Alamo Sandstone</div> <div>Kirtland Shale</div> <div>Naashoibito Member</div> <div>upper shale member</div> <div>Farmington Sandstone Member</div> <div></div> <div>not studied</div>	<div>Ojo Alamo Formation</div> <div>Kirtland Formation</div> <div>Naashoibito Member</div> <div>De-na-zin Member</div> <div>Farmington Member</div> <div>Hunter Wash Member</div> <div>Bisti Member</div> <div>Fossil Forest Member</div> <div>Ne-nah -ne-zad Member</div>	<div>Ojo Alamo Formation</div> <div>Kimбето Member</div> <div>Naashoibito Member</div> <div>De-na-zin Member</div> <div>Farmington Member</div> <div>Hunter Wash Member</div> <div>Bisti Bed</div> <div>Fossil Forest Member</div> <div>Ne-nah -ne-zad Member</div>

FIGURE 2. Development of stratigraphic nomenclature of the Fruitland, Kirtland and Ojo Alamo formations, San Juan Basin, New Mexico.

cent advances in tyrannosaurid taxonomy (Currie, 2003; Currie et al., 2003), in some respects they remain poorly understood. Isolated tyrannosaurid teeth pertaining to *Albertosaurus* and/or *Daspletosaurus* are known from both local faunas, but their generic and specific identity remains problematic.

RADIOISOTOPIC AGES

Fassett and Steiner (1997) published a series of $^{40}\text{Ar}/^{39}\text{Ar}$ ages undertaken by J. Obradovich on Fruitland-Kirtland ash beds. These ages provide

very precise numerical calibration of the Fruitland-Kirtland succession (Figs. 3, 5).

The base of the Fruitland Formation lies slightly below ash DEP (Dog Eye Pond), which has been dated at 75.56 ± 0.41 Ma. The Fruitland-Kirtland contact lies below Ash 2, dated at 74.55 ± 0.29 Ma, and Ash 4, dated at 74.11 ± 0.62 Ma, which lies on top of a persistent coal bed. Fassett and Steiner (1997) reported Ash 2 (74.55 Ma) as being in the Fruitland Formation and Ash 4 (74.11) as being at the base of the Kirtland Formation. However, both ash beds, in the drainage of Hunter Wash, are actually

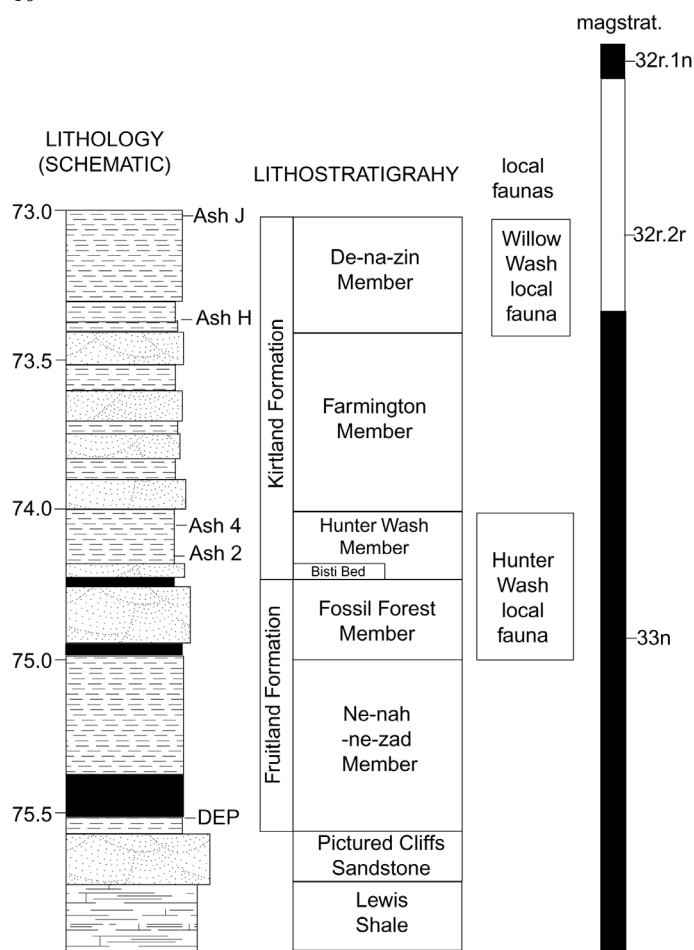


FIGURE 3. Summary of the stratigraphy, geochronology and magnetostratigraphy of the Fruitland and Kirtland formations, San Juan Basin, New Mexico.

in the Hunter Wash Member of the Kirtland Formation. Ash 2 is in the north facing cut-bank of the wash at UTM 12 S, 729213E, 4020100N (NAD 27), in the middle part of the Hunter Wash Member. Ash 4 is stratigraphically higher in the south-facing cut-bank of Hunter Wash at UTM 12 S, 754040E, 4022208N. Near the top of the Kirtland Formation, in the highest part of the De-na-zin Member, lie two other ashes, Ash H, dated at 73.37 ± 0.28 Ma and Ash J, dated at 73.04 ± 0.25 Ma (Lucas and Sullivan, 2000b; Sullivan et al., 2005b).

MAGNETOCHRONOLOGY

Radioisotopic ages and biostratigraphy securely place the Fruitland-Kirtland interval in the Campanian, so Maastrichtian age assignments based on magnetic-polarity stratigraphy are untenable (Lindsay et al., 1981; Butler and Lindsay, 1985; Butler et al., 1977; Lucas and Schoch, 1982). Most of the Fruitland and lower Kirtland are of normal polarity, a long normal chron assigned to chron 33n by Fassett and Steiner (1997). The reversed polarity upper Kirtland Formation is correctly assigned to chron 32r.2r (Fassett and Steiner, 1997; Lerbekmo and Braman, 2002). Therefore, the Kirtlandian encompasses the younger part of chron 33n and most of chron 32r.2r (Figs. 3, 5).

KIRTLANDIAN LVA DEFINED

Sullivan and Lucas (2003a) defined the Kirtlandian LVA as the time interval between the end of the Judithian and the beginning of the Edmontonian (Figs. 1, 5). The first appearance of the ceratopsid dinosaur *Pentaceratops sternbergii* defines the beginning of the Kirtlandian (and end of the Judithian). The first appearance of the hadrosaurid dinosaur

Edmontosaurus regalis Lambe defines the beginning of the Edmontonian (and end of the Kirtlandian).

Sullivan and Lucas (2003a) originally used the first appearance of *Pachyrhinosaurus canadensis* to define the beginning of the Edmontonian. However, we note that Brinkman (2003) cites the occurrence of *Pachyrhinosaurus* in the Wapiti Formation in the Grand Prairie region of Alberta, a thick nonmarine Campanian-early Maastrichtian sequence that correlates with part of the lower Bearpaw Formation. It is unclear whether this taxon is *P. canadensis* Sternberg, but we have amended our original definition (Sullivan and Lucas, 2003a, 2003c) to better define the end of the Kirtlandian (= beginning of the Edmontonian) based on the first appearance of *Edmontosaurus regalis*.

Radioisotopic ages and magnetostratigraphy indicate that the Kirtlandian represents approximately 2.2 million years, from 75 Ma to 72.8 Ma, and coincides with the upper part of magnetopolarity chron 33n and the lower part of magnetopolarity chron 32r (Fig. 5).

The characteristic Kirtlandian land-vertebrate assemblage includes the vertebrate fossil assemblages from the upper Fruitland Formation and the Kirtland Formation (Hunter Wash, Farmington and De-na-zin members), San Juan Basin, New Mexico. The characteristic Kirtlandian fauna thus is a composite of both the Hunter Wash local fauna and the Willow Wash local fauna of previous authors.

Principal Correlatives

The principal correlatives (vertebrate faunas) of the Kirtlandian characteristic land-vertebrate assemblage are vertebrate faunas from the: lower part of the Bearpaw Formation of Montana, USA and Alberta, Canada; Williams Fork Formation, northwestern Colorado; upper part of the Kaiparowits Formation, south-central Utah; Fort Crittenden Formation, southeastern Arizona; Ringbone Formation, southwestern New Mexico; Corral de Enmedio and Packard formations of the Cabullona Group, Sonora Mexico; El Gallo Formation, Baja California del Norte, Mexico; and possibly the lower part of the Cerro del Pueblo Formation, Coahuilla, Mexico. Part of the upper shale member of the Aguja Formation, Big Bend region, Texas, may also be correlative to part of the Kirtlandian (Fig. 4). The doubt in the recognition of a definitive age is the result of inadequate taxonomic data and questionable magnetostratigraphic correlations (see discussion below). The upper shale member of the Aguja Formation is thought to span the middle Campanian to early Maastrichtian (Sankey and Gose, 2001; Sankey, 2005).

Kirtlandian Index Fossils

Sullivan and Lucas (2003a) chose *Pentaceratops sternbergii* as the principal index fossil of the Kirtlandian because it is restricted to, and found throughout, the entire Kirtlandian interval in the San Juan Basin and is a well-documented taxon. However, we note here that it is more common in the upper Fruitland (Fossil Forest Member) and lower Kirtland (Hunter Wash Member) than in the upper Kirtland (De-na-zin Member). Outside the San Juan Basin, *P. sternbergii* is now known with certainty from the Williams Fork Formation of northwestern Colorado (Lucas et al., 2006c). Other Kirtlandian index taxa include: the short-crested lambeosaurine hadrosaur *Parasaurolophus cyrtocristatus* and the flat-headed hadrosaurid *Kritosaurus navajovius* (also see unique taxa below).

Unique Taxa

Taxa that are considered by us to be characteristic of the Kirtlandian land-vertebrate Age" include: *Melvius chauliodous*, *Denazinemys ornata*, *Boremys grandis*, *Neurankylus baueri*, *Adocus bossi*, *A. kirtlandius*, *Thescelus hemispherica*, "*Aspideretes*" *ovatus*, "*Plastomenus*" *robustus*, *Denazinosuchus kirtlandicus*, *Saurornitholestes robustus*, *Anasazisaurus horneri* Hunt and Lucas, *Kritosaurus navajovius*, *Naashoibitosaurus ostromi*, *P. tubicen*, *Nodocephalosaurus kirtlandensis*, and *Prenocephale goodwini*. Note that any of the unique taxa listed here are potential index fossils provided they are recognized with certainty outside the type area (i.e., outside of the Fruitland and Kirtland exposures in the San Juan Basin,

TABLE 1. Non-mammalian fossil vertebrates from the Fruitland and Kirtland formations, San Juan Basin, New Mexico. HWlf = Hunter Wash local fauna; WWlf = Willow Wash local fauna.

TAXON GROUP	SUBGROUP	GENUS/SPECIES	HWlf	WWlf
Chondrichthyes	Rhinobatidae	<i>Myledaphus bipartitus</i>	X	X
Actinopterygii	Amiidae	<i>Melvius chauliodous</i>	X	X
Testudines	Bothremydidae	Bothremydidae, n. gen., <i>barberi</i>	X	
	Baenidae	<i>Denazinemys ornata</i>	X	
		<i>Denazinemys nodosa</i>	X	X
		<i>Boremys grandis</i>	X	
		<i>Neurankylus baueri</i>	X	X
		<i>Thescelus hemispherica</i>	X	X
	Dermatemydidae	<i>Adocus bossi</i>	X	
		<i>Adocus kirtlandius</i>	X	
	Nanhsiungchelyidae	<i>Basilemys nobilis</i>	X	X
	Trionychidae	<i>Aspideretes ovatus</i>	X	
		" <i>Plastomenus</i> " <i>robustus</i>	X	X
Crocodylia	"Mesosuchia"	<i>Denazinosuchus kirtlandicus</i>		X
	Crocodylidae	<i>Brachychampsa montana</i>	X	X
		<i>Deinosuchus rugosus</i>	X	
		cf. <i>Leidyosuchus</i> sp.	X	X
Dinosauria	Tyrannosauridae	<i>Daspletosaurus</i> sp.	X	X
	Ornithomimidae	<i>Ornithomimus antiquus</i>	?	X
	Dromaeosauridae	<i>Sauornitholestes robustus</i>	?	X
	Titanosauridae	<i>Alamosaurus sanjuanensis</i>		X
	Hadrosauridae	<i>Anasazisaurus horneri</i>	X	
		<i>Kritosaurus navajovius</i>	?	X
		<i>Naashoibitosaurus ostromi</i>		X
		<i>Parasaurolophus crytocristatus</i>	X	
		<i>Parasaurolophus tubicen</i>		X
	Ankylosauridae	<i>Nodocephalosaurus kirtlandensis</i>	?	X
	Pachycephalosauridae	<i>Prenocephale goodwini</i>	?	X
		<i>Stegoceras validum</i>	X	
	Ceratopsidae	<i>Pentaceratops sternbergii</i>	X	X
		Centrosaurinae, n. gen., n. sp.		X

New Mexico). A list of these taxa, their respective holotypes, stratigraphic horizons of the holotypes, and principal published references is presented in the Appendix.

CORRELATION WITHIN THE WESTERN INTERIOR OF NORTH AMERICA

Outside of the San Juan Basin, we consider several North American

stratigraphic units to be of Kirtlandian age: 1) the lower part of the Bearpaw Formation, Alberta-Montana; 2) the upper part of the Kaiparowits Formation, south-central Utah; 3) most of the Williams Fork Formation, "Mesa Verde Group," of northwestern Colorado; 4) the Ringbone and Fort Crittenden formations of southwestern New Mexico and southeastern Arizona, respectively; 5) the part of the upper shale member of the Aguja Formation, Big Bend region, Texas; 6) El Gallo Formation, Baja California

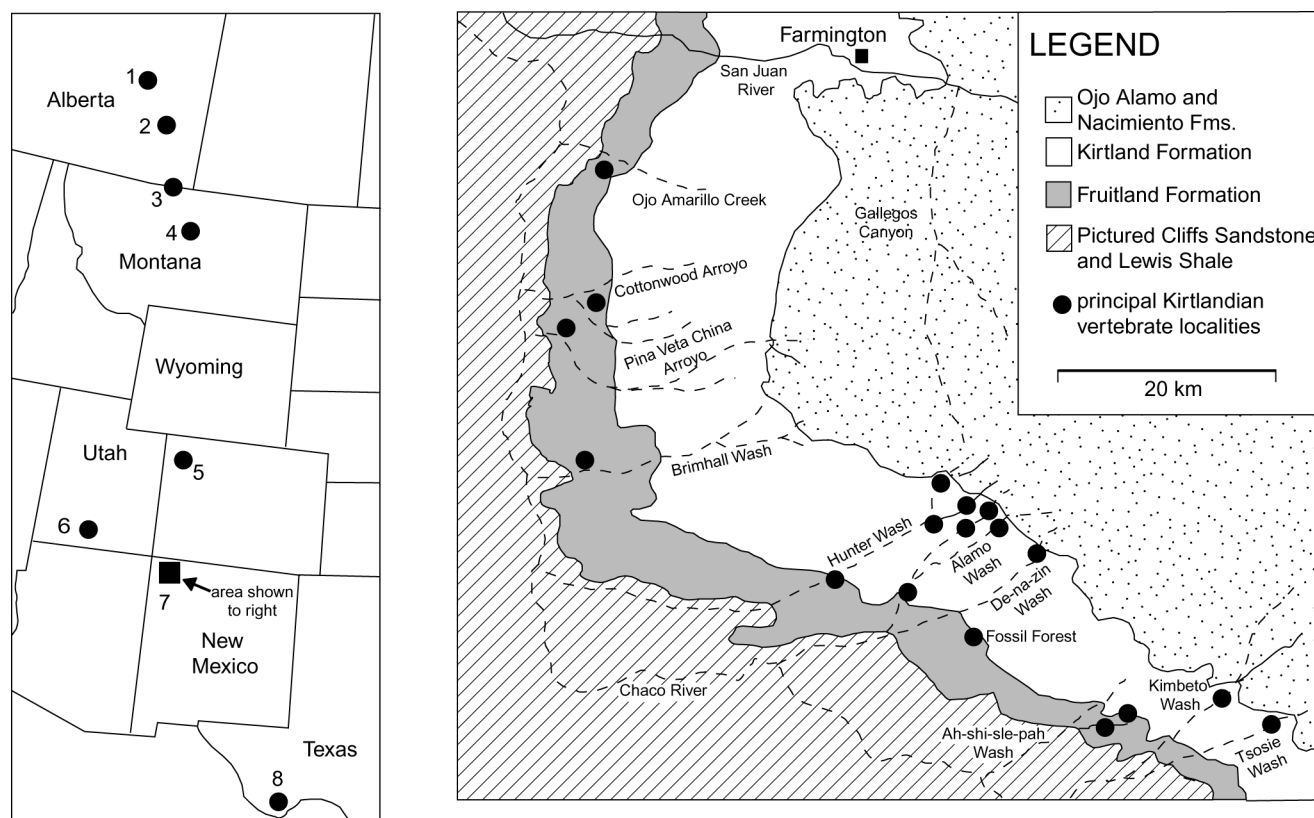


FIGURE 4. Location map (left) of principal late Campanian/early Maastrichtian dinosaur-bearing units in western North America (exclusive of Mexico, see text). 1. Horseshoe Canyon and Bearpaw formations, Alberta; 2. Dinosaur Park and Oldman formations, Alberta; 3. Milk River Formation, Alberta; 4. Bearpaw, Two Medicine and Judith River formations, Montana; 5. Williams Fork Formation, northwestern Colorado; 6. Kaiparowits Formation, Utah; 7. Fruitland and Kirtland Formations, New Mexico; and 8. upper shale member of the Aguja Formation, Big Bend region, Texas. Map (right) of part of the west-central San Juan Basin, New Mexico, showing the principal dinosaur collecting areas of Kirtlandian age. The Ringbone Formation, New Mexico; El Gallo, Enmedio, Packard and Cerro del Pueblo formations, Mexico (not shown).

del Norte, Mexico; and 7) Corral de Enmedio and Packard formations of the Cabullona Group in northeastern Sonora, Mexico (Fig. 2). The lower part of the Cerro del Pueblo Formation of the Difunta Group in the Parras Basin, Coahuilla, Mexico, may be correlative to the latest Kirtlandian.

BEARPAW FORMATION, ALBERTA-MONTANA

Horner (1979) reported on a limited assemblage of terrestrial vertebrates from the marine Bearpaw (Shale) Formation of south-central Montana. Among these vertebrates is a hadrosaurine partial skull and postcranial skeleton that he concluded is “nearly identical with the holotype” of *Gryposaurus* (*Kritosaurus*) *notabilis* Lambe (Horner, 1979), referring it to “*Hadrosaurus notabilis*.” The genus *Kritosaurus* is consistent with a Kirtlandian age, but both *Gryposaurus notabilis* and “*Kritosaurus incurvimanus* (Parks)” are also known from the Dinosaur Park Formation (Eberth et al., 2001), which is slightly older than the beginning of the Kirtlandian (Fig. 5). However, Kirkland et al. (2006) believe *Kritosaurus* and *Gryposaurus* are distinct taxa. Other fossil vertebrates (dinosaurs) from the Bearpaw Formation reported by Horner (1979) are too fragmentary for positive identification and thus are not useful for correlation.

The main argument for the Bearpaw Formation as a correlative of the upper part of the Fruitland/Kirtland sequence is its relative stratigraphic position and its age based on ammonite biozonation and radioisotopic dating. The base of the Bearpaw Formation is just below the *Baculites compressus* ammonite biozone (dated at 73.35 ± 0.35 Ma by Obradovich, 1993), whereas an ash in the lowermost part (30 meters of the base) of the Bearpaw Formation has now been dated at $74.8 \text{ Ma} \pm 0.11$ (Eberth et al., 2001; 2005). Thus, the Dinosaur Park Formation-Bearpaw Formation contact is older, near 75 Ma. The top of the Bearpaw Formation, and base of the Horseshoe Canyon Formation (= beginning of the Edmontonian), co-

incides with the chron 32n-32r boundary dated at 72 Ma (Eberth et al., 2001; Lerbekmo and Braman, 2002). We therefore place the base of the Kirtland Formation at 75 Ma, between Ash 2 (74.55 Ma) and the DEP ash (75.56 Ma), approximately at the base of the Fossil Forest Member of the Fruitland Formation.

Williams Fork Formation, Northwestern Colorado

In northwestern Colorado, Newman (1987) correlated the base of the Williams Fork Formation (“Mesa Verde Group”) to the upper part of the Lewis Shale and the top of the Williams Fork Formation to the lower part of the De-na-zin Member of the Kirtland Formation, based on palynomorphs (*Trudopollis-Myrtaceipollenites-Pseudoplicapollis* zone, or data point) and ammonite zonation using the then-current numerical calibration (radioisotopic dates) of the Campanian and Maastrichtian. Noll (1988) correlated the Williams Fork Formation to the late Campanian-early Maastrichtian based on the correlation of Newman (1987). Recent work by Lerbekmo and Braman (2002) has pushed the Campanian-Maastrichtian boundary up to 68.5 Ma, placing the Williams Fork Formation well within the late Campanian. The Campanian-Maastrichtian boundary has also been placed at 70.6 Ma (Gradstein and Ogg, 2004).

The correlation of the Williams Fork Formation presented by Newman (1987) has recently been corroborated by vertebrate fossil evidence presented in an unpublished master’s thesis by Diem (1999), who documented a Williams Fork Formation occurrence of the ceratopsid *Pentaceratops*, the first known occurrence of this dinosaur from outside of the San Juan Basin. We agree that the specimen is referable to *Pentaceratops* (see below and Lucas et al., 2006c). Diem and Archibald (2005) corroborated a Campanian correlation of the Williams Fork Formation, indicating that it spans several ammonite zones, from the *Didymoceras*

cheyennense Zone (74.5 Ma) to the *Baculites baculus* Zone (70.5 Ma).

In addition to *Pentaceratops* from the Williams Fork Formation, Diem (1999) reported *Troodon formosus* Leidy, *Dromaeosaurus albertensis* Matthew and Brown, *Saurornitholestes langstoni*, indeterminate tyrannosaurids, *Richardoestesia gilmorei* Currie, Rigby and Sloan, *Ankylosaurus magniventris* Brown, indeterminate nodosaurids, *Thescelosaurus neglectus* Gilmore, indeterminate hadrosaurid, and the mammals *Mesodma thompsoni* Clemens, *Cimolodon nitidus* Clemens, ?*Cimolodon* sp., *Cimolomys* sp., *Meniscoessus* aff. *M. intermedius* Fox, *M. major* Sahni, *M. collemensis* Lillegraven, ?*Paracimexomys* sp., *Turgidodon rhaister* (Clemens), *T. russelli* (Fox), *Alphadon marshi* Simpson, *Alphadon wilsoni* Lillegraven, *Pediomys cooki* Clemens, *Aquiladelphus incus* Fox, *Eodelphis* sp., and *Aenigmadelphys* sp. nov. Many of these identifications are problematic as they are either based on limited material and/or are inconsistent with known temporal distributions. Others are of form taxa (i.e., teeth of *Thescelosaurus*).

For example, the presence of the Lancian ankylosaurid *Ankylosaurus magniventris* in the Williams Formation is highly doubtful. The identification of this taxon rests on a single tooth. Moreover, this dinosaur is a well-established Lancian species that is unknown in older strata. Teeth pertaining to the Kirtland Formation ankylosaurid *Nodocephalosaurus kirtlandensis* are not known (Sullivan, 1999), and it is more probable that the Williams Fork Formation tooth pertains to this or some other pre-Lancian ankylosaurid (possibly *Euoplocephalus tutus* (Lambe), see Vickaryous and Russell, 2003), although identification of ankylosaurids based on isolated teeth is considered problematic (Coombs, 1990). Thus, the taxonomic identifications of many of the fossil vertebrates from the Williams Fork fauna can be considered “tenuous” because of the small sample size and their fragmentary nature. Nonetheless, Diem (1999) noted that the Fruitland/Kirtland formations and Williams Fork Formation share a number of taxa in common, suggesting that they are similar in age. The presence of the ceratopsid *Pentaceratops* in the Williams Fork Formation, coupled with the shared taxa noted by Diem (1999), demonstrates a Kirtlandian “age” for the vertebrate-bearing strata of this unit.

Kaiparowits Formation, Utah

In southern Utah, part of the Kaiparowits Formation yields a vertebrate assemblage of Kirtlandian age. Fishes from the Kaiparowits and other formations in the region of the Grand Staircase-Escalante National Monument, Utah, have only been reported in a very cursory way, focusing on patterns of evolutionary turnover at higher taxonomic levels (Kirkland and Eaton, 2002). McCord (1997b, 1998b) reported on a polyglyphandontine lizard and the microherpetofaunas from the Kaiparowits Plateau, while also noting palynomorphs, plant fossils, invertebrates, fishes (based on an unpublished account by J. I. Kirkland), dinosaurian and mammalian faunas from the Dakota, Straight Cliffs, Wahweap and Kaiparowits formations. Most of the taxa McCord (1997b) recognized from the Kaiparowits Formation included many Lancian species, together with some known from the Cenozoic, suggesting that a good number of these identifications are erroneous. Indeed, many of these identifications were based on very fragmentary material and plesiomorphic features.

McCord recognized the following Lancian taxa from the Kaiparowits Formation: the salamanders *Opisthotriton kayi* Auffenberg, *Prodesmodon copei* Estes (= *Cuttysarkus mcnellyi* Estes), *Lisserpeton bairdi* Estes, *Habrosaurus dilatus* Gilmore, *Adelphesiren olivae* Goin and Auffenberg; the frog *Scotiophryne pustulosa* Estes; the turtle *Compsemys victa* Leidy; and the lizards *Chamops segnis* Marsh, *Leptochamops denticulatus* (Gilmore), *Odaxosaurus piger* (Gilmore), *Exostinus lancensis* Gilmore, and *Parasaniwa wyomingensis* Gilmore. Judithian taxa recognized by McCord (1997b) include: the salamander *Scapherpeton tectum* Cope, and the lizards *Paraglyphanodon gazini* Gilmore, a new genus and species of teiid and cf. *Palaeosaniwa canadensis* Gilmore (along with a questionable helodermatid and two indeterminate anguids). He also identified the Miocene caudate *Albanerpeton inexpectum* Estes and Hoffstetter and Mi-

ocene frog *Eopelobates* sp., and the Paleocene turtle cf. *Hoplochelys* sp., Cenozoic taxon identifications that we doubt are correct, together with an indeterminate trionychid and booid. We note here that his subsequent paper (McCord, 1998b) was an abbreviated version of his previous work (McCord, 1997b) and that most of these taxa were cited at the genus level only.

McCord (1998a) named a new polyglyphandontine lizard, *Manangysaurus saueri*, based on a dentary fragment with three teeth. Voci and Randall (2003) have recently reviewed the polyglyphandontine lizards from the Kaiparowits Formation, but because this work is still ongoing we cannot assess the current state of polyglyphandontid species diversity. Gillette and Hayden (1997) reported the occurrence of the crocodile *Bernissartia* sp., but Hutchison et al. (1998) thought that this may be a misidentified *Brachychampsia*. We note that reference to *Denazinosuchus kirtlandicus* (Lucas and Sullivan, 2003) may be the correct identification, but no definitive statement regarding its identity can be made at this time.

Additional lower vertebrates from the Kaiparowits Formation have been reviewed by Hutchison et al. (1998). They presented an “uncritical list” of lower vertebrates from the Kaiparowits Formation. Again, much of what they reported is cursory in nature, and many of the taxa have not been substantiated or critically evaluated. Their overview has been supplemented by other brief reports, including those of Parrish (1999), Imhof (2002), Sampson et al. (2002), Smith et al. (2003), and Zanno et al. (2005) on dinosaurs and other vertebrates, Zanno and Sampson (2003) on a new caenagnathid, and Smith et al. (2004) on a putative new ceratopsid close to *Pentaceratops sternbergii*. In addition, Gillette et al. (2002) reported on a tail with skin impressions of an indeterminate hadrosaur (tentatively considered a lambeosaurine) from the Kaiparowits Formation.

Cifelli and Johanson (1994) and named a marsupial, *Aenigmadelphus archeri*, from the Kaiparowits Formation. Later, Eaton et al. (1999) documented the fossil vertebrates from the Kaiparowits Formation and assigned them a Campanian age based on analysis of palynomorphs and the absence of Maastrichtian-age mammals. This assessment was reinforced by Eaton (2002), who documented the Judithian “age” mammals *Dakotamys magnus* (Archibald) and *Mesodma archibaldi* Eaton from the Kaiparowits Formation and considered them to be slightly older than the type Judith River fauna. Eaton et al. (1999) previously recognized the first occurrences of the “insectivore” *Gypsonictops* sp. and the turtle *Boremys* sp. in the Kaiparowits, and cited the former taxon as an index fossil, assigning it a Judithian age. In addition, they noted the turtle *Compsemys* sp. is a common element, and its presence in the Fruitland Formation has been reported by Hunt and Lucas (1992). Most of the taxa listed by Eaton et al. (1999) are not identified to the species level. Moreover, as with the Oldman and Dinosaur Park formations (see Eberth et al., 2001), several of the Kaiparowits lower vertebrate taxa, especially amphibians and lizards (squamates), were referred to Lancian and younger (Cenozoic) taxa, which we consider suspect, as noted above. A partial skeleton of an indeterminate lambeosaurine, thought to be *Parasaurolophus* sp., was reported by Titus et al. (2001). In addition, the Lancian enaniornithine bird *Avisaurus* sp. was cited as occurring in the Kaiparowits (Hutchison, 1993; Stidham and Hutchison, 2001). A new species of *Avisaurus* (*A. gloriae* Varricchio and Chiappe) was documented in the Campanian Two Medicine Formation of Montana (Varricchio and Chiappe, 1995), and the Kaiparowits taxon may represent this latter species.

Eaton et al. (1999) recognized that the multituberculates from the Kaiparowits Formation “do not compare well to any fauna and include many new forms.” In his more recent paper, Eaton (2002) named several new mammal taxa: *Mesodma archibaldi*, *M. minor*, *Cimolodon foxi* Eaton, *Kaiparomys cifelli* Eaton, ?*Cimolomys butleria* Eaton and *Cedaromys hutchisoni* Eaton and recognized *Dakotamys magnus* as a new combination of the taxa *Cimexomys magnus* (Sahni, 1972) and *Paracimexomys magnus* (Archibald, 1982). It is likely that some of these new taxa may become index fossils for the Kirtlandian if they are identified in the vertebrate fauna of the Fruitland and Kirtland formations.

The only unequivocal Kirtlandian index fossil in the Kaiparowits

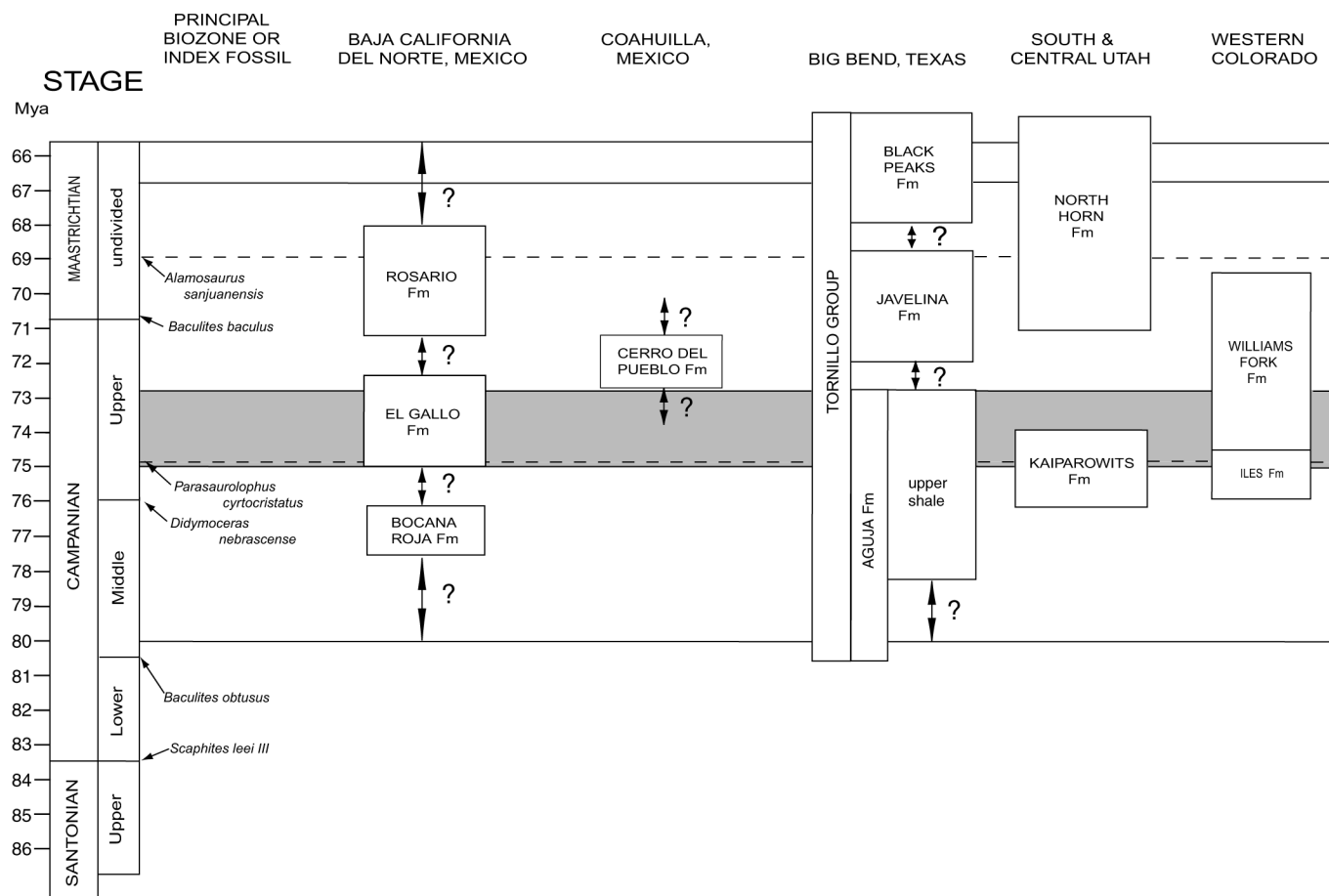


FIGURE 5. Correlation of the Kirtlandian LVA to other North American Upper Cretaceous sections and ages (modified from Sullivan, 2003). Correlation data based, in part, on Cifelli et al. (2004), Eberth (2005), Eberth et al. (2001, 2004), Fassett and Steiner (1997), Gradstein and Ogg (2004), Ogg (2004), Renne et al. (1991), Rodgers et al. (2005), Stankey and Gose, (2001), Lerbekmo and Braman (2002), and Obradovich (1993).

vertebrate fauna is the lambeosaurine *Parasaurolophus cyrtocristatus*, known from two specimens with cranial material from the Kaiparowits Formation (one still undescribed in the collections of the University of California, Museum of Paleontology-Berkeley) and one from the Fruitland/Kirtland (Weishampel and Jensen, 1979; Sullivan and Williamson, 1999). Based on the presence of this dinosaur in the Kaiparowits Formation we believe that this formation is correlative, at least in part, with the upper Fruitland and lower Kirtland formations, and thus is Kirtlandian in age. This assessment has recently been confirmed by radioisotopic dates for the Kaiparowits Formation that range from 76.0 to 74.2 for the lower and upper parts of the formation, respectively (Imhof and Albright, 2003; Roberts and Deino, 2004; Roberts et al., 2005). The occurrence in the Kaiparowits Formation of *P. cyrtocristatus* (Sampson personal commun., 2004) at about 75 Ma supports correlation to the occurrence of *P. cyrtocristatus* in the upper part of the Fruitland Formation and lower part of the Kirtland Formation (Fig. 5).

Peterson and Kirk (1977) correlated the Kaiparowits Formation to the upper Campanian and the underlying Wahweap Formation to the uppermost lower Campanian and the lowermost upper Campanian based on a combination of factors including the recognition of transgressive-regressive cycles, ammonite zonation and benonite marker beds. Later, Eaton (1991) altered this correlation, placing the boundary of the Wahweap and overlying Kaiparowits formations as (questionably) coincident with the lower and upper Campanian boundary. Eaton (1991) noted that the fossil mammals from the Kaiparowits are certainly of Campanian age, and may

be as old as early Campanian (i.e., Aquilan) based on the similarity of the fauna to that of the Milk River Formation. However, Eaton (2002) subsequently argued for a Judithian age of the Kaiparowits based on multituberculate mammals. Indeed, Eaton's (2002) Judithian correlation was adopted by Roberts et al. (2005), even though their own radioisotopic ages from the Kaiparowits Formation indicate its middle to upper strata are younger than 74.8 MA, so they overlap the Kirtlandian. Clearly, available radioisotopic ages and vertebrate biostratigraphy indicate a correlation of the upper Fruitland and lower Kirtland and part of the Kaiparowits Formation, which means the Kaiparowits encompasses strata of Judithian and Kirtlandian age.

Fort Crittenden Formation, Southeastern Arizona

The first published record of Cretaceous vertebrate fossils from southeastern Arizona is Stoyanow (1949), who reported fossils of fish, turtles, and "*Gorgosaurus*" from Upper Cretaceous strata (Fort Crittenden Formation) in Adobe Canyon in the Santa Rita Mountains near Tucson. Since this report, several workers have collected vertebrate fossils in Adobe Canyon, making this the only diverse Cretaceous vertebrate assemblage from southeastern Arizona.

Documented fossil vertebrates from the middle member of the Fort Crittenden Formation in Adobe Canyon are the chondrichthyan *Myledaphus bipartitus* Cope, lepisosteid gars, pycnodontid fish, the bowfin *Melivius* sp., cf. *Pachyrizodus* sp., the turtles *Basilemys* (previously identified by Heckert et al., [2003] as *Adocus*), "*Plastomenus*," and indeterminate

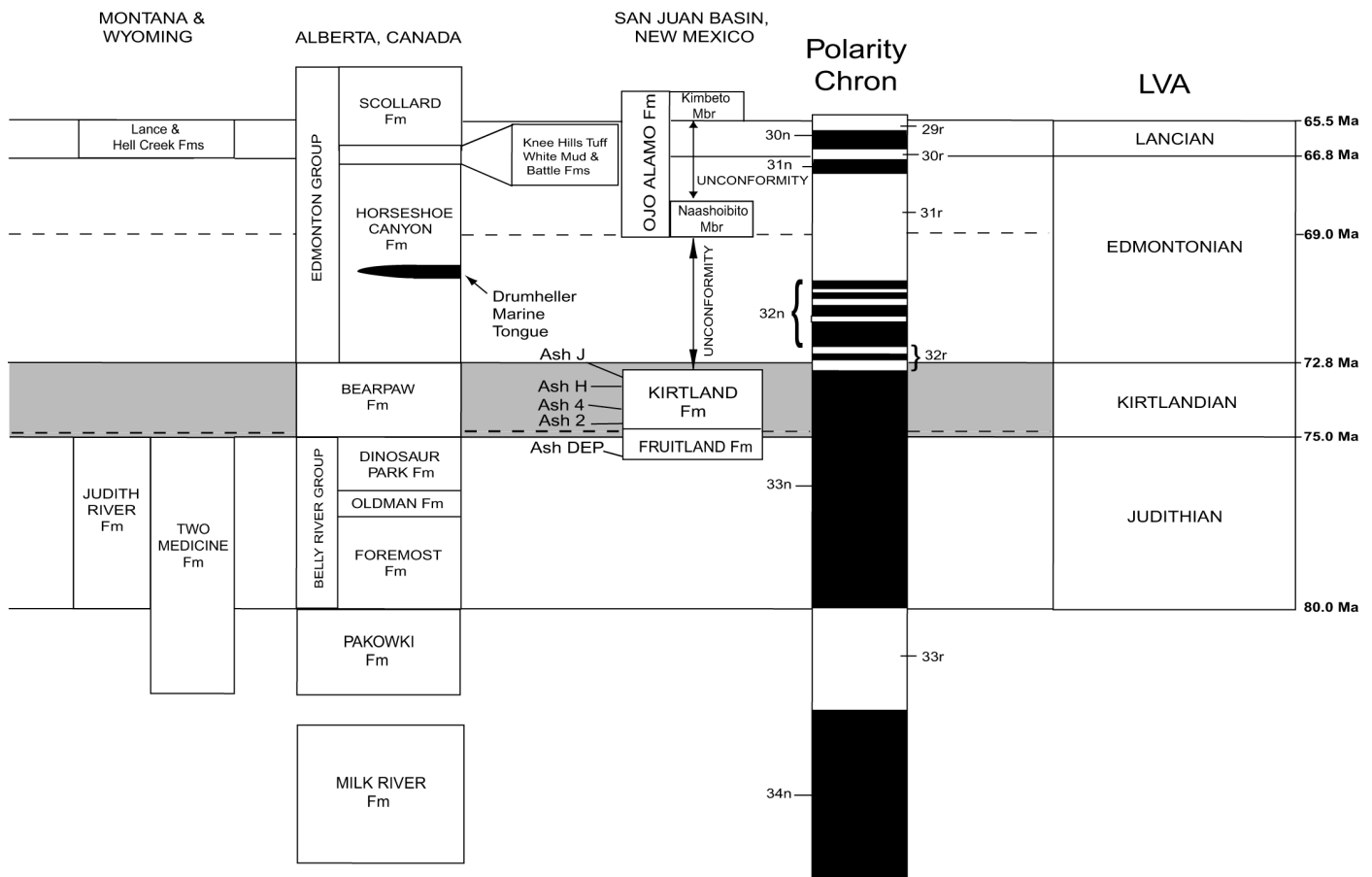


FIGURE 5. (continued)

trionychids, as well as tyrannosaurid, dromaeosaurid, titanosaurid, hadrosaurid and ceratopsid dinosaurs (Miller, 1964; Miller and Schwab, 1966; McCord and Tegowski, 1996; Ratkevich and Duffek, 1996; McCord, 1997a; Heckert et al., 2003; Lucas and Heckert, 2005). Ratkevich (1994) and Ratkevich and Duffek (1996) reported multituberculate, marsupial and placental mammal teeth from the Fort Crittenden Formation in Adobe Canyon, but we have examined these teeth and believe they are of Paleocene age and therefore not from the Fort Crittenden Formation.

Ratkevich and Duffek (1996) also listed several additional taxa from the Fort Crittenden Formation, including the salamanders *cf. Opisthotriton* sp. and *cf. Scapherpeton* sp., the turtle "*Aspideretes*" sp., the crocodilian *Allognathosuchus* sp., teiid and anguid lizards, and Pterosauria(?). These identifications have not been documented, and may not be reliable. For example, *Allognathosuchus* has no Cretaceous records (Lucas, 1992a; Lucas and Estep, 2000), and the report from Adobe Canyon is based on an isolated scute (Ratkevich and Duffek, 1996, fig. 1) better identified as *Alligatoroidea* indet. Furthermore, we consider the isolated small theropod teeth illustrated by Ratkevich and Duffek (1996, figs. 3-4) and identified as *cf. Saurornitholestes* and *cf. Richardoestes* as indeterminate Dromaeosauridae.

Regardless of the uncertainty of some identifications, the Fort Crittenden Formation vertebrates do provide a tentative basis for a Kirtlandian age assignment (note the presence of *Melivius*). Nevertheless, a plausible case for assigning the Fort Crittenden Formation vertebrates a Kirtlandian age can be made based on radioisotopic ages:

1. The Salero Formation volcanic rocks that conformably overlie

the Fort Crittenden Formation have yielded K/Ar ages on biotite of 70-74 Ma (Bikerman and Damon, 1966; Drewes, 1971; Hayes and Drewes, 1978; Inman, 1987). Hayes (1986, 1987) reported a biotite K/Ar age of ~75 Ma for volcanics beneath the Fort Crittenden Formation in the Canelo Hills. These ages indicate a Campanian age for the Fort Crittenden Formation, and suggest it is about 74 Ma, within the Kirtlandian time interval.

2. The Fort Crittenden Formation is an obvious correlative of the Ringbone Formation of southwestern New Mexico (Hayes, 1970; Lawton et al., 1993; Lucas et al., 1995, 2000; Basabivazo, 2000). Both units are remarkably similar lithologically, occupy the same stratigraphic position and have similar vertebrate fossil assemblages (Lucas et al., 1990, 1995; Anderson et al., 1998). Ar^{40}/Ar^{39} ages on the basal andesites of the Hidalgo Formation, which overlies the Ringbone Formation in the Little Hatchet Mountains of New Mexico, are about 70.5 and 71.4 Ma. These dates support a late Campanian age for the Ringbone Formation (Lawton et al., 1993), and thus, by correlation, the Fort Crittenden Formation.

Ringbone Formation, Southwestern New Mexico

Lucas et al. (1990, 2000) and Anderson et al. (1998) reported on a low diversity dinosaur fauna from the Ringbone Formation of southwestern New Mexico. They identified indeterminate hadrosaurids from skin impressions and vertebrae, and tentatively identified a carnosaur tooth and vertebra as *cf. Albertosaurus*, while noting that reference to *Daspletosaurus* was equally plausible. Although hampered by age constraints, Lucas et al. (1990) noted lithologic and depositional similarities between the Ringbone Formation and Fort Crittenden Formation of south-

eastern Arizona, and both units are constrained to the Campanian by radioisotopic dates (see above). The occurrence of *Albertosaurus* or *Daspletosaurus*, although not robust, is certainly consistent with a Campanian or more specifically Kirtlandian “age” assignment. We therefore conclude that the Ringbone Formation may be of Kirtlandian “age,” though this age assignment is tentative.

Aguja Formation (Upper Shale Member), Big Bend Region, Texas

Colbert and Bird (1954) reported on *Deinosuchus* (= *Phobosuchus*) *riograndensis* (Colbert and Bird) from the lower part of the upper shale member of the Aguja Formation, Big Bend region of Texas (Sankey and Gose, 2001; Sankey, 2005) which is considered to be of middle Campanian age. Rowe et al. (1992), Weil (1992), Cifelli (1994) and Sankey (2001, 2005) reported on various microvertebrate assemblages from higher up in the upper shale member of the Aguja Formation, and Tomlinson (1997) reported on the turtles, most of which come from the upper shale member. A new marine protostegid, *Terlingualchelys fischbecki*, was documented from the lower Rattlesnake Mountain Sandstone Member (Aguja Formation) by Lehman and Tomlinson (2004), and is considered to be of middle Campanian age. Rowe et al. (1992) identified several taxa, many based on very fragmentary material, and summarized these, and others, in an “uncritical tabulation” of the vertebrates from the Aguja Formation, and assigned them a Judithian age.

Lehman (1989) reported the occurrence of the ceratopsid *Chasmosaurus mariscalensis*, (now *Agujaceratops*, see Lucas et al., 2006c) from the upper shale member of the Aguja Formation, and noted the occurrence of *Kritosaurus*, *Panoplosaurus*, *?Stegoceras*, indeterminate ornithomimids and tyrannosaurids previously cited by him (Lehman, 1985b). Wagner (2001) reported an unnamed new species of *Kritosaurus* from the lower shale member, and additional material of “*Kritosaurus* cf. *K. navajovius*” from the upper shale member of the Aguja Formation. Sankey (2001) identified several dinosaur taxa from the upper shale member of the Aguja Formation based on teeth, including an indeterminate pachycephalosaur, indeterminate hadrosaur, indeterminate ceratopsid, indeterminate tyrannosaurid, *Saurornitholestes* cf. (*S.*) *langstoni*, *Richardoestes* cf. (*R.*) *gilmorei* and a new species *R. isosceles*, together with other indeterminate taxa. In a subsequent paper Sankey (2005) provided a revised list of taxa, including mammals. Unfortunately, taken at face value, these taxa do not provide a precise correlation to the Kirtlandian or Judithian. The reported occurrence of *Kritosaurus* in the upper shale member of the Aguja Formation (Lehman, 1985b; Davies and Lehman, 1989; Sankey, 2001) is of interest. However, its presence is based largely on unpublished work of Lehman (1985b) cited by Lehman (1989) and Sankey (2001), which have yet to be unequivocally demonstrated. Interestingly, *Kritosaurus* was not listed among the taxa recovered from the Aguja Formation (Sankey, 2005), yet she claims the fauna is part of Lehman’s “southern *Kritosaurus* fauna.” Investigations concerning the occurrence of *Kritosaurus* in the Cerro del Pueblo Formation (Coahuila, Mexico) by Kirkland et al. (2006) may eventually support this identification, if the two units are demonstrated to be co-eval and if diagnostic features are preserved.

Although there is uncertainty regarding many of the taxonomic vertebrate identifications, recent advances in magnetostratigraphy have placed the lower part of the upper shale member of the Aguja Formation at approximately 74 Ma (Sankey and Gose, 2001). Thus, we tentatively consider the part of the upper shale member of the Aguja Formation to be equivalent, in part, to the Kirtland Formation (Fig. 5). However, given the uncertainty of some of the critical taxonomic identifications and their biostratigraphic occurrences, we recognize that some may be Judithian “age.”

El Gallo Formation, Baja California Del Norte, Mexico

A series of tuff dates (Ar/Ar method) from the El Gallo Formation of Baja California del Norte, Mexico (Renne et al., 1991) demonstrate that this unit is largely coeval to the Kirtlandian interval. An age of 74.87 ± 0.05

Ma for the age of the base of the La Escarpa Member of the El Gallo Formation, coincides with the base of the Bearpaw Formation (or top of the Dinosaur Park Formation) of Alberta (Eberth, 2005). The youngest tuff date, taken from within the El Disecado Member, is 73.59 ± 0.09 Ma, a date that is slightly older than Ash H from the San Juan Basin (Fassett and Steiner, 1997), which is approximately equivalent to the Farmington Member of the Kirtland Formation. Indeed, the rest of the El Disecado Member above this date is probably equivalent to the De-na-zin Member (73.37 ± 0.18 – 73.04 ± 0.25 Ma).

The vertebrate fauna of the El Gallo Formation has been reported on by Lillegraven (1972), Morris (1967, 1973, 1974, 1981), and more recently by Nydam (1999) and Montellano et al. (2005). In a preliminary report on the fossil mammals, Lillegraven (1972) identified *Mesodma* cf. *M. formosa*, *?Stygimys* sp., *Pedionomys* sp. and an unnamed new genus of indeterminate insectivore. Fragments pertaining to unidentified multituberculates were also noted (Lillegraven, 1972).

Morris (1967) first referred the hadrosaur remains (incomplete premaxilla, maxilla, incomplete jugal, ischia, and an anterior series of caudal vertebrae) from the El Gallo Formation to *Hypacrosaurus*, then to cf. *Lambeosaurus* sp. (Morris, 1973). Later, Morris (1981) gave the name *?Lambeosaurus laticaudus* to this same material. In an earlier paper (Morris, 1974) he listed other lower vertebrates, most notably a *?discoglossid* frog, a *?paleobatrachid* frog, the teiid lizard “cf. *Paraglyphanodon*,” an unidentified bird bone, and some isolated carnosaur teeth, which he believed to be similar to *Labocrania anomala* (Molnar, 1974). Parenthetically, the bird (*Alexornis antecedens*) was named and described by Brodkorb (1976), but it came from the underlying Bocana Roja Formation. More recently, Nydam (1999) named the teiid lizard species *Polyglyphanodon bajaensis* based on an isolated tooth, and new, more complete material was reported by Montellano et al. (2005). Parenthetically, the material referred to as “cf. *Paraglyphanodon*” by Morris (1974) was actually *Polyglyphanodon*, and the former taxon may be a juvenile representative of the latter (Estes, 1983, p.78).

Overall, the fossil vertebrates from the El Gallo Formation are still poorly known, and it is difficult to assess their true composition and relationships to other Western Interior late Campanian faunas at this time. It should be noted here that Molnar’s (1974) theropod *Labocrania anomala*, presumably a carnosaur, is from the “La Bocana Roja” Formation, a unit that lies unconformably below the El Gallo Formation. Interestingly, Molnar (1974) considered *L. anomala* to be similar, in some respects, to the Asian *Chilantaisaurus maortuensis* from the Lower Cretaceous of China, *Indosaurus matleyi* from the Lameta beds of India, and *Szechuanosaurus campi* from the Jurassic of China. The age of the “La Bocana Roja” Formation is presumed to be late Campanian, and possibly as old as Cenomanian (Molnar, 1974); correlation of this stratigraphic unit to rocks of Judithian or Kirtlandian age is not possible at present.

Corral De Enmedio and Packard Formations, Cabollona Group, Sonora, Mexico

In northeastern Sonora, Mexico, the Corral de Enmedio and Packard formations of the Cabollona Group are correlative to the Fort Crittenden Formation of southeastern Arizona and the Ringbone Formation of southwestern New Mexico (González-León and Lawton, 1995; Lucas et al., 1995). The vertebrate fauna of the Corral de Enmedio and Packard formations is fragmentary but includes Lepisosteidae indeterminate, *Melvius* sp., Trionychidae indeterminate, Eusuchia indeterminate, the teiid lizard *Chamops segnis*, Hadrosauridae indeterminate, Ceratopsidae indeterminate, and isolated teeth identified as “cf. *Albertosaurus* sp.” (Lucas et al., 1995). This may be an assemblage of Kirtlandian age, based largely on correlation to the Fort Crittenden and Ringbone formations.

Cerro Del Pueblo Formation, Difunta Group, Coahuila, Mexico

Murray et al. (1960a, b) reported dinosaur remains (*Monoclonius* and hadrosaurs) from Unit “A” of the Difunta Group in the eastern part of

the Parras Basin and noted that dinosaur bones had been found at a number of localities in the border region of the states of Coahuila and Nuevo León, Mexico. They correlated these dinosaur fossils to the Campanian (i.e., “Bellyriveran” and “Montanan” age). Subsequent work by Murray et al. (1962) recognized formal subdivisions of the Difunta Group. The lowest of these, the Cerro del Pueblo Formation, has been the source of most the dinosaur remains from the Difunta Group.

In addition to the fossil material noted by Murray et al. (1960a, b), recent collecting in the Cerro del Pueblo Formation has produced an array of vertebrate taxa including fragmentary hadrosaur skulls, hadrosaur skin impressions and skeletal remains, chondrichthyans, osteichthyans, testudines, crocodyliforms, an indeterminate pterodactylid, and dinosaurs including ceratopsids, tyrannosaurids, dromaeosaurids, ornithomimids, and possible troodontids (Hernández-Rivera et al., 1995; Rodríguez-De La Rosa and Cevallos-Ferriz, 1998; Hernández-Rivera and Delgado-de Jesús, 2000; Kirkland and Aguillón-Martínez, 2002), and dinosaur tracks (Aguillón et al., 1998). Of particular interest are the accounts of cf. *Melivius* sp., and the indeterminate goniopholid reported by Rodríguez-De La Rosa and Cevallos-Ferriz (1998). It is possible that additional, and more complete, material may indicate that these are *Melivius chauliodous* and *Denazinosuchus kirtlandicus*, respectively, relegating them to index fossil status and reinforcing a Kirtlandian age for this vertebrate fauna. A caudal vertebra from the Cerro del Pueblo Formation, originally identified as belonging to a brachiosaur (Kirkland et al., 2000a), is now known to be an anterior caudal of a hypacrosaur hadrosaurid.

Previously considered early Maastrichtian in age, the Cerro del Pueblo Formation is now considered to be of late Campanian age (Aguillón et al., 1998; Eberth et al., 2004; Kirkland et al., 2000b; 2006) based on magnetostratigraphy and ammonite correlation and zonation. A partial skeleton and other skeletal remains from this formation have been referred to *Kritosaurus* (Hernández-Rivera, 1997; Kirkland et al., 2000b; 2006), suggesting that the Cerro del Pueblo Formation may be partly correlative to the Kirtlandian. However, we note that Eberth et al. (2004) and Kirkland et al. (2006) assessed the age of the Cerro del Pueblo Formation at $72.3\text{--}71.3 \pm 0.5$ Ma. Based on our revised duration for the Kirtlandian age presented in this paper, the Cerro del Pueblo Formation is early Edmontonian age (=latest Campanian).

The fauna of the Cerro del Pueblo Formation has been compared to another poorly known fauna in Chihuahua, northern Mexico (Montellano-Ballestros et al., 2000) based on overall similarity. However, the comparison is so general, and the evidence so weak and incomplete, that this correlation is considered premature.

Therefore, we conclude that the magnetostratigraphic data provided by Eberth et al. (2004) indicate that the Cerro del Pueblo Formation is early Edmontonian, and it may be below the Kirtlandian-Edmontonian boundary if the margin of error exceeds the 72.8 Ma datum.

THE KIRTLANDIAN FAUNA AND COMPARISONS TO OTHER LATE CRETACEOUS NORTH AMERICAN LAND-VERTEBRATE “AGES”

Here, we discuss the taxonomy of the vertebrate faunas that characterize the Kirtlandian LVA (i.e., the Hunter Wash local fauna and Willow Wash local fauna). We also comment on the composition of the faunas that characterize the Judithian and Edmontonian LVAs where appropriate.

Pisces (Fishes)

Sharks, rays, batoids, and various bony fishes have been reported from the Fruitland and Kirtland formations (e.g., Gilmore, 1916; Armstrong-Ziegler, 1980; Hutchinson and Kues, 1985; Hall and Wolberg, 1989; Hall, 1991). A number of elasomobranch taxa were reported by Eberth et al. (2001) from the Dinosaur Park Formation, and only a couple from both the Oldman and the Horseshoe Canyon formations. One taxon, *Myledaphus bipartitus*, has been reported from all four units and is ubiquitous in the Upper Cretaceous of western North America (Campanian-Maastrichtian),

so it has little biostratigraphic utility. The actinopterygian *Melivius chauliodous* (Hall and Wolberg, 1989; Grande and Bemis, 1998) is restricted to Kirtlandian-age strata. If other specimens of *Melivius* from outside the San Juan Basin can be referred with confidence to this species, then *M. chauliodous* will be a Kirtlandian index taxon.

Amphibia

Armstrong-Ziegler (1980) and Hall (1991) reported a few amphibians from the upper Fruitland Formation, but we regard the taxonomic identifications, many of which have been assigned to Lancian or younger (Paleocene) taxa, as suspect because of the fragmentary nature of the material. A few amphibians have been reported from the Oldman, Dinosaur Park and Horseshoe Canyon formations. Among them are the lissamphibians *Scapherpeton tectum*, named for type material from the “Judith River,” and *Opisthotriton kayi*, type material from the Lance Formation (Cope, 1876; Auffenberg and Goin, 1959; Auffenberg, 1961; Estes, 1964; Estes et al., 1969). These caudate taxa have also been recognized in Paleocene deposits of Wyoming and Montana (Estes, 1975; Sullivan, 1991). If these identifications are correct, then it is clear that lissamphibians at the species level have little utility in Late Cretaceous biostratigraphic correlation.

Testudines (Turtles)

Hay (1908) and Gilmore (1916, 1919, 1935) named a variety of Fruitland-Kirtland turtles based on nearly complete shells (carapaces and plastra). Wiman (1933) described a number of new specimens collected by, and purchased from, C. H. Sternberg (Hunt et al., 1992; Sullivan and Williamson, 1997) but did not name any new Late Cretaceous taxa. Gaffney (1972) synonymized several species, including *Neurankylus baueri* with *N. eximus* Lambe and *Thescelus hemispherica* with *T. insiliens* Hay. However, we favor resurrecting some taxa based on the presence of taxonomically useful characters recognized by the original authors. For example, the Fruitland/Kirtland specimens of *Neurankylus baueri* are, in part, distinguished by having the first suprapygal bone shorter and wider than that in *N. eximus* (holotype CMN 1504) from the Oldman Formation of Alberta (Gaffney, 1972, fig. 39). Also, the sutures are offset between costals (6, 7 and 8) and the eighth neural and first suprapygal in *N. eximus*, whereas the costal sutures lie coincident with those between the neurals in *N. baueri*. Although, Gaffney (1972) believed it to be unwise to use the keels to distinguish species, these other characters suggest specific differences. *Thescelus hemispherica* (Gilmore, 1935) was synonymized with *T. insiliens* by Gaffney (1972), although the former is, in part, characterized by a deeply emarginated nuchal and non-constricted carapace. We note too that the pattern of carapace bones-to-scutes in the Uppsala specimens (PMU.R22 and PMU.R23) originally identified by Wiman (1933) as *T. raptiens* Hay and *T. insiliens*, respectively, differs from what Gaffney (1972, fig. 42) illustrated for *T. insiliens* based on a composite of AMNH 1108 and 6606. Gilmore (1935) succinctly diagnosed *T. hemispherica* based on sound morphological features, so we tentatively place the Fruitland/Kirtland *Thescelus* specimens in this species. Parenthetically, Gaffney (1972, p. 299) stated that he did not examine, at that time, the Fruitland/Kirtland specimens in the collections of the University of Uppsala and relied solely on the published work of Wiman (1933) for his analyses of these taxa.

We thus recognize five species of Fruitland-Kirtland baenid turtles: *Denazinemys nodosa*, *Denazinemys ornata*, *Boremys grandis*, *Neurankylus baueri*, *Thescelus hemispherica*; two adocids: *Adocus bossi* and *A. kirtlandius*; one nanhsiungchelyidid: *Basilemys nobilis* (first reported from the Ojo Alamo Formation by Hay, 1911); and two trionychids: “*Aspideretes*” *ovatus* and “*Plastomenus*” *robustus* (Gilmore, 1916, 1919, 1935; Wiman, 1933; Lucas and Sullivan, 2006). We reported (Sullivan and Lucas, 2003a) that Eugene Gaffney (American Museum of Natural History, New York) will be naming a new bothremiid genus from the Hunter Wash Member. We note that Tomlinson (1997) reported on a bothremiid (*Bothremys* sp.) from the Aquja Formation (upper shale member) of Texas based on an incomplete carapace and plastron. We are unable

to determine whether this is the same species as the Fruitland specimen, as they are known from non-comparable remains. We note, too, that McCord (1996) attempted a biostratigraphic review of turtle genera for the Upper Cretaceous through Paleocene strata of the San Juan Basin based solely on specimens in the University of Arizona collection. Unfortunately, some of his identifications are inaccurate (i.e., “*Trionyx*” for trionychid material from the Kirtland Formation) while others are incomplete (the notable absence of *Basilemys* and “*Plastomenus*” in both the Kirtland and Fruitland formations according to McCord). The range zones presented by McCord (1996) for the San Juan Basin turtles are also seriously flawed, not only in the identification of taxa but also with respect to their actual temporal distribution.

A more thorough and detailed analysis of Late Cretaceous turtle biogeography (and biostratigraphy) has been recently published by Holroyd and Hutchison (2002) for the Hell Creek Formation (North Dakota) and Lance and Ferris formations (Wyoming), and by Brinkman (2003) for the Upper Cretaceous of Alberta, Canada. While these strata share some turtle genera in common with the Fruitland/Kirtland formations (e.g., *Adocus*, *Denazinemys* [= “*Baena*”], *Basilemys*, *Neurankylus*, *Thescelus*), it is unclear how the species differ, if at all. Species-level taxonomy of Upper Cretaceous testudines is not well understood, and it may prove that some of the Fruitland/Kirtland species of *Adocus*, “*Aspideretes*,” *Basilemys*, *Denazinemys* and *Neurankylus* are synonymous with other species of the same genera. The middle Campanian taxon *Aspideretoides* (Gardner et al., 1995) has not been identified from the Fruitland/Kirtland formations, but some of the newly collected trionychid material may prove to be referable to this genus. Parham and Hutchison (2003) named a new taxon, the eucryptodiran turtle *Judithemys sukhonovi* Parham and Hutchison, known from a number of specimens from the Dinosaur Park Formation of Alberta, but it is not known from the Fruitland and Kirtland formations of New Mexico. The turtle “*Plastomenus*” *robustus* represents an unnamed genus. We expect that a number of the Fruitland/Kirtland turtle taxa, especially the more well-documented ones such as “*Plastomenus*” *robustus*, are potential index taxa of the Kirtlandian LVA (see the list of unique taxa above).

Squamata (Lizards and Snakes)

A few lizards, and one snake, have been reported from the Fruitland Formation by Armstrong-Ziegler (1978, 1980) and Sullivan (1981). Many of Armstrong-Ziegler’s fossil lizard identifications are incorrect, including cf. *Gerrhonotus* sp. and *Leptochamops denticulatus* Gilmore (see Good, 1988; Gao and Fox, 1996), and the aniliid snake *Coniophis cosgriffi* Armstrong-Ziegler is known from a single specimen whose diagnosis is inadequate (Rage, 1984). Sullivan (1981) referred an incomplete dentary from the Fruitland Formation to the teiid lizard cf. *Chamops segnis*, an identification that has been questioned (Gao and Fox, 1996). Gao and Fox (1991, 1996) named a number of lizard taxa, many of them new teiids, from the Oldman and Dinosaur Park formations. They also named a new species of anguid lizard, *Odaxosaurus priscus* Gao and Fox, which cannot be readily distinguished from *O. piger*, so it is probably a *nomen dubium* because it is in all respects plesiomorphic and synonymy with *O. piger* cannot be demonstrated. Hall (1991) reported *Meniscognathus altmani*, *Odaxosaurus piger* and an indeterminate snake from the Fruitland Formation. We doubt the identifications of the two former taxa based on the inadequate nature of the material. Fossil squamates are not well documented from the Fruitland and Kirtland formations, so they are not helpful for correlation.

Choristodera (Champsosaurs)

One centrum (KUPV 103310) was reported by Hall (1991) from the Fruitland Formation. Four additional specimens are now known: (NMMNH 1882) also from the Fruitland Formation; and the other three (NMMNH 1794, 3498 and 3506), each represented by a single, isolated vertebra/centrum, from the Kirtland Formation.

Crocodylia

One “mesosuchian,” *Denazinosuchus* (= *Goniopholis*) *kirtlandicus*, and three crocodylids (*Brachychampsia montana*, *Deinosuchus robustus* and *Leidyosuchus* sp.) have been reported from the Fruitland and Kirtland formations (Wiman, 1932; Armstrong-Ziegler, 1980; Hall, 1991; Lucas, 1992a; Lucas and Sullivan, 2003; Sullivan and Lucas, 2003b; Lucas et al., 2006b,d). The giant crocodylian, *Denosuchus rugosus* is now known from the Fossil Forest Member of the Fruitland Formation (Lucas et al., 2006d). The presence of ?*Thoracosaurus* sp., based on isolated, strongly recurved anterior teeth (Armstrong-Ziegler, 1980), cannot be substantiated, and the occurrence of *Leidyosuchus* sp. is also problematic. *Leidyosuchus* (*L. canadensis*) is known from the Dinosaur Park Formation, and *L. sp.* has been reported from the Oldman Formation (Eberth et al., 2001). Sullivan and Lucas (2003b) reported *Brachychampsia montana* in the De-na-zin Member of the Kirtland Formation and synonymized *B. sealeyi* Williamson (from the early Campanian interval of the Menefee Formation, New Mexico) with *B. montana*, thus establishing a long stratigraphic range for this species (early Campanian-late Maastrichtian) and rendering it useless as an index taxon. The putative occurrence of “cf. *Wannanosuchus* sp.” reported by Hall (1991) is erroneous. Only the “mesosuchian” *Denazinosuchus kirtlandicus* is a potential crocodylian index taxon of the Kirtlandian LVA.

Dinosauria

Tyrannosauridae

Several tyrannosaur/carnosaur genera have been cited as coming from the Fruitland and Kirtland formations, but Carr and Williamson (2000) determined that most of the diagnostic material should be identified as *Daspletosaurus* sp. They thus concluded that records of *Albertosaurus* sp., based on isolated teeth, are not defensible, but that a new, undescribed specimen, from the Hunter Wash Member of the Kirtland Formation, is similar to *Albertosaurus*, although they referred it to cf. *Daspletosaurus*. Carr (personal commun., 2002) stated that another newly reported specimen, consisting of a partially articulated skull and skeleton from the Farmington Member, may represent a new genus and species.

Daspletosaurus torosus Russell is known solely from the Oldman Formation, while *Daspletosaurus* sp. is known from the Dinosaur Park Formation (Currie, 2003). *Gorgosaurus libratus* Lambe is restricted to the Dinosaur Park Formation, and *Albertosaurus sarcophagus* Osborn is known solely from the Horseshoe Canyon Formation. It may be that the newly discovered specimen from the Kirtland Formation represents a distinct taxon that is readily distinguishable from Judithian and Edmontonian tyrannosaurid species.

Ornithomimidae

Only one diagnostic ornithomimid specimen, identified as *Ornithomimus antiquus* (Leidy), is known from the Kirtland Formation (Sullivan, 1997). *Ornithomimus edmontonicus* Sternberg, which is known from the Dinosaur Park and Horseshoe Canyon formations (Eberth et al., 2001), and *O. velox* Marsh, a Lancian taxon, reported also from the Kaiparowits Formation (DeCourten and Russell, 1985), are considered subjective junior synonyms of *O. antiquus* (Sullivan, 1997). Previous reports of cf. *Ornithomimus* sp. and *Struthiomimus* sp. from the Fruitland and Kirtland formations, respectively, are less certain (Lucas et al., 1987; Hunt and Lucas, 1992). The rarity and incomplete nature of most ornithomimid specimens makes them poor index fossils.

Dromaeosauridae

Sullivan and Lucas (2000b) documented a left frontal of the dromaeosaurid “*Saurornitholestes langstoni*” from the De-na-zin Member of the Kirtland Formation, but Sullivan (2006b) now recognizes a new species, *S. robustus*, based on a left frontal, and has referred all previous Kirtland specimens to this species. Three isolated teeth of “*S. langstoni*” were reported from the Fruitland Formation of the Fossil Forest area (Hall,

1991), but we have not been able to verify their taxonomic identity. In addition, isolated teeth of indeterminate dromaeosaurs were previously reported from both the Fruitland and Kirtland formations (Armstrong-Ziegler, 1980; Lucas et al., 1987). *Saurornitholestes langstoni* is known from the Dinosaur Park (= Judith River) Formation (Sues, 1978; Eberth et al., 2001; Currie, 2005). Isolated teeth from the Oldman Formation have been referred to cf. *Saurornitholestes* sp., and isolated teeth of *Saurornitholestes* have been reported from the late Campanian and Maastrichtian strata in the Western Interior. (Eberth et al., 2001; Currie, 2005). Unfortunately, the teeth are not reliable species indicators, and although they are “*Saurornitholestes*-like” they may not represent that genus, but rather a taxon similar to it (D. Brinkman, pers. commun., 2005). For the most part, dromaeosaurid skeletal remains are so rare and fragmentary that they are currently not useful for correlation. However, it would seem that *Saurornitholestes robustus*, which is unique and restricted to the De-na-zin Member of the Kirtland Formation, is a potential index taxon of the Kirtlandian.

Theropoda – *incertae sedis*

Armstrong-Ziegler (1980) reported on several isolated teeth from the Fruitland Formation, which she referred to the Lancian form taxon *Paronychodon lacustris* Cope. A single non-serrated tooth (SMP VP-1354), with wrinkled enamel, has recently been recovered from the De-na-zin Member of the Kirtland Formation, and is identified as cf. *Paronychodon lacustris*. It is identical to those from the Milk River Formation of Alberta (Baszio, 1997, pl. 6, figs. 81, 82). In addition, teeth identified as cf. *Paronychodon* sp. are known from the Oldman, Dinosaur Park, Horseshoe Canyon and Scollard formations (Eberth et al., 2001; Currie, 2005), so it has no utility as an index fossil.

Titanosauridae

Caudal vertebrae and a single tooth (the latter we now assign to a crocodyliform) from the De-na-zin Member of the Kirtland Formation were recently referred to the sauropod form taxon *Alamosaurus sanjuanensis* Gilmore (Lucas and Sullivan, 2000b; Sullivan and Lucas 2000a, 2003a). The titanosaurid caudal vertebrae from the De-na-zin Member reported by us may also be referable to *A. sanjuanensis*, a taxon also known from younger strata (i.e., Naashoibito Member of the Ojo Alamo Formation, New Mexico; North Horn Formation, Utah; Javelina/Black Peaks formations, Texas). Montellano-Ballesteros (2003) recently reported on the occurrence of titanosaurid caudal vertebrae from Chihuahua, Mexico, and McCord (1997a) reported on sauropod material (a vertebra) from the Campanian Fort Crittenden Formation of Arizona (also see Lucas and Heckert, 2005). No sauropod remains are known from the Upper Cretaceous dinosaur-bearing units of Alberta. Finally, the recent report of a brachiosaur caudal from the Cerro del Pueblo Formation of Coahuila, Mexico (Kirkland et al., 2000a) is erroneous (see above). Thus, the temporal range of sauropods in the North American Late Cretaceous is Kirtlandian through Edmontonian.

Hypsilophodontidae

A single tooth from the Fruitland Formation was questionably referred to *Thescelosaurus* sp. by Hutchinson and Kues (1985), but the tooth is not diagnostic of any primitive ornithischian taxon. The hypsilophodontid *Orodromeus makelai* Horner and Weishampel is known from the Oldman Formation, and *Parksosaurus warreni* (Parks) is known from the Horseshoe Canyon Formation. An indeterminate (genus and species) hypsilophodontid was also reported from the Dinosaur Park Formation (Eberth et al., 2001).

Hadrosauridae

Five hadrosaurids have been named from the Fruitland/Kirtland formations, three hadrosaurines—*Kritosaurus navajovius*, *Anasazisaurus horneri*, *Naashoibitosaurus ostromi*— and two lambeosaurines—*Parasaurolophus cyrtocristatus* and *Parasaurolophus tubicen* (Brown,

1910; Hunt and Lucas, 1993; Ostrom, 1961, 1963; Sullivan and Williamson, 1999; Wiman, 1931). Hunt and Lucas (1993) suggested that *K. navajovius* is a *nomen dubium* and that *A. horneri* and *N. ostromi* are distinct, but Williamson (2000) concluded that *K. navajovius* is valid and that *A. horneri* and *N. ostromi* are junior subjective synonyms of *K. navajovius*. Lucas et al. (2006a) documented the distinctiveness of *K. navajovius* and *A. horneri*. *Gryposaurus notabilis* and “*Kritosaurus*” (= *Gryposaurus*) *incurvimanus* are known from the Dinosaur Park Formation (Eberth et al., 2001). The occurrence of *Kritosaurus* in the Perras Basin (Cerro del Pueblo Formation) of Mexico, and its distinctiveness to *Gryposaurus* (Kirkland et al., 2006) is of extreme interest. On the face of it, it would seem that *Gryposaurus* is a predecessor of *Kritosaurus*, the latter is only known with certainty from the Kirtland Formation (De-na-zin Member) and now the Cerro del Pueblo Formation.

Williamson (2000) synonymized *P. cyrtocristatus* with *P. tubicen*, and misrepresented the conclusions reached by Sullivan and Williamson (1999) regarding the coexistence of *P. cyrtocristatus* and *P. tubicen*. There is no morphological reason to suggest that they represent the same species, moreover, they are separated stratigraphically by nearly three millions years. Mere sympatry of the two species, which has never been demonstrated, is not a conclusive argument for synonymy. Furthermore, the differences in the morphology of the narial crests of *P. cyrtocristatus* and *P. tubicen* are so extreme, both internally and externally, that they most likely represent distinct taxa and not sexual dimorphs. We regard *P. cyrtocristatus* as an index taxon for correlation outside the San Juan Basin because it is also known from the Kaiparowits Formation of Utah (Sullivan and Williamson, 1999). Presently, we retain all five named Fruitland-Kirtland hadrosaurids as valid, pending further study.

Nodosauridae and Ankylosauridae

Nodosaurids and ankylosaurids have been reported from the Fruitland and Kirtland formations based largely on isolated dermal plates and limb bones. Identifications of the nodosaurid ?*Panoplosaurus* and ankylosaurid ?*Euoplocephalus* were based on a left scapula and right humerus, respectively (Lucas et al., 1987). Definite occurrence of *Euoplocephalus* has not been demonstrated in the San Juan Basin. Interestingly, the species *E. tutus* is known from the Oldman, Dinosaur Park and the Horseshoe Canyon formations of Alberta as well as the Two Medicine Formation of Montana (Eberth et al., 2001; Vickaryous and Russell, 2003). The only diagnostic ankylosaurian in the San Juan Basin is the ankylosaurid *Nodocephalosaurus kirtlandensis* from the De-na-zin Member (Sullivan, 1999), and it is unique to the Kirtland Formation, so it may be an index taxon of the Kirtlandian. Isolated osteoderms, similar to those on the holotype skull (SMP VP-900), have recently been recovered from the Hunter Wash Member, as well as a shoulder spine (Sullivan and Fowler, 2006).

The nodosaurid *Edmontonia rugosidens* Gilmore is known from the Dinosaur Park Formation, and *E. longiceps* Sternberg is from the Horseshoe Canyon Formation. Previously, we (Sullivan and Lucas, 2003a) stated that *Edmontonia australis* Ford, a taxon named by Ford (2000) based on a pair of medial cervical scutes (osteoderms) from the Naashoibito Member (Ojo Alamo Formation *not* the Kirtland Formation) is not diagnostic to species and thus is a *nomen dubium*. Positive evidence for *Edmontonia* in the San Juan Basin is lacking. Hall (1991) recognized *Edmontonia* sp. from the Fruitland Formation based on a single broken and worn tooth (KUPV 103388), an identification we do not accept due to the insufficient material upon which it is based. Lastly, the nodosaurid *Glyptodontopelta mimus* Ford, a taxon erected on a section of pelvic osteoderms (USNM 8610), and is from the Ojo Alamo Formation (Naashoibito Member) (Gilmore, 1919), is also a *nomen dubium* (Sullivan and Lucas, 2003a).

Pachycephalosauridae

Only a few pachycephalosaur specimens are known from the Fruitland and Kirtland formations. Williamson and Carr (2002) briefly reported on an indeterminate frontoparietal from the upper Fruitland Forma-

tion that we have identified as *Stegoceras validum* (Sullivan and Lucas, 2006a). Williamson and Carr (2003) named "*Sphaerotherolus*" *goodwini* based on a partial skull from the De-na-zin Member, which had previously been assigned to the genus *Prenocephale* (Williamson, 1999; Williamson and Sealey, 1999; Sullivan, 2000). They also referred an isolated left dentary, squamosal and cranium fragment from the Farmington Member of the Kirtland Formation to cf. *S. goodwini*, without justification. Sullivan (2003) synonymized *Sphaerotherolus* with *Prenocephale* and recognized the species *goodwini* as valid. *Prenocephale goodwini* is known only from the Kirtland Formation and may be an index taxon of the Kirtlandian. A pachycephalosaurid (*Stegoceras* [sensu lato]) has been reported from the Kaiparowits Formation of Utah by Hutchison et al. (1998). *Stegoceras validum* Lambe is restricted to the Dinosaur Park Formation of Alberta, the upper Fruitland Formation of New Mexico, and questionably occurs in the Oldman Formation of Alberta (Eberth et al., 2001; Sullivan, 2003; Sullivan, 2005; Sullivan, 2006a; Sullivan and Lucas, 2006). The taxon *Hanssuesia sternbergi* (Brown and Schlaikjer) has the same occurrence as does *Prenocephale brevis* (Lambe), which also is known from the Horseshoe Canyon Formation. *Prenocephale edmontonensis* (Brown and Schlaikjer) is restricted to the Horseshoe Canyon Formation (Sullivan, 2003). The genus *Prenocephale* is known from the Nemegt Formation of the Mongolian Peoples Republic, from the Oldman, Dinosaur Park, Horseshoe Canyon formations of Alberta, Canada, and the Fruitland, Kirtland, Lance and Hell Creek formations (USA) (Maryańska and Osmólska, 1974; Sullivan 2000, 2003, 2006a).

Ceratopsidae

The ceratopsid *Pentaceratops sternbergii* (Osborn, 1923) (= *P. fenestratus* Wiman, 1930) is the most conspicuous dinosaur taxon in the Fruitland and Kirtland formations. It is most common in the upper Fruitland and lower Kirtland. Only a few specimens are known from the De-na-zin Member. Nonetheless, *P. sternbergii* is present throughout the entire Fruitland-Kirtland stratigraphic interval, so it serves as the principal index taxon of the Kirtlandian. Other ceratopsids, not referable to *Pentaceratops*, are also known and are from the De-na-zin Member. A squamosal and fragments of a parietal (SMP VP-1314) of an indeterminate centrosaurine have recently been collected, and this demonstrates the occurrence of this subfamily of ceratopsids in the Kirtlandian.

We note that Diem (1999) properly identified the occurrence of *Pentaceratops* in the Williams Fork Formation, reiterated by Diem and Archibald (2000). However, Diem and Archibald (2005) have reassessed this taxonomic assignment in light of the paper by Holmes et al. (2001), who provided an incomplete assessment of *Pentaceratops* with respect to the species of *Chasmosaurus*. Although we agree that a thorough, more complete phylogenetic analysis of the Chasmosaurinae needs to be undertaken (Holmes et al., 2001), the species have been adequately revised to allow for characterization and recognition despite morphologic variation within the species (Godfrey and Holmes, 1995; Lehman, 1993, 1998). Furthermore, we disagree that the species of *Chasmosaurus* are insufficient for characterization and note that the chasmosaurine genera and species are also stratigraphically segregated, contrary to statements made by Lehman (1998). We have reviewed the attributes cited for SDNHM 43470 and concur with the original generic identification given by Diem (1999), because this specimen agrees in every respect with *Pentaceratops sternbergii* (Lucas et al., 2006c). The frill of *Pentaceratops sternbergii* differs from that of *Chasmosaurus russelli* Sternberg (notably CMN 2280) in possessing the following: 1) a more robust parietal; 2) deeper incised posteromedian emargination; 3) pronounced (expansion) lateral ends of the parietal, forming the "M" shape posterior emargination; 4) well-developed epoccipitals along the posterior margin of the parietal; and 5) well-developed, paired, median and up-turned epoccipitals. SDNHM 43470 is referable to *Pentaceratops sternbergii* based on its robust morphology, deeply incised posteromedian emargination of the parietal, and the large, well-developed epoccipital on the right medial margin of the parietal. Differ-

ences in the morphology of the epoccipitals, compared to larger, more massive specimens, are attributed to the fact that the specimen is of a subadult. This combination of characters precludes possible referral to any species of *Chasmosaurus*.

Mammalia

Fossil mammals have been reported from the Fruitland or Kirtland formations by Clemens (1973), Flynn (1986), and Rigby and Wolberg (1987). Flynn (1986) summarized the taxa from the Hunter Wash local fauna. These included the following multituberculates: an indeterminate "plagiaulacoid," *Paracimexomys judithae* Sahni, *P. n. sp.*, cf. *Mesodma senecta* Fox, *M. n. sp.* or *Cimexomys* cf. *C. antiquus* Fox, cf. *Kimbetohia campi* Simpson, *Cimolodon electus* Fox, *Meniscoessus intermedius*, cf. *Essonodon* n. sp., and an indeterminate eucosmodontid; the metatherians cf. *Alphadon marshi*, cf. *A. wilsoni*, *Alphadon* n. sp. A, *Alphadon* n. sp. B, *Alphadon?* n. sp., cf. *Pediomyss cooki*; and the eutherians *Gypsonictops* n. sp. and cf. *Cimolestes* sp.

Rigby and Wolberg (1987) recognized *Alphadon halleyi* Sahni, cf. *Eodelphis* sp., *Gypsonictops* cf. (*G.*) *lewisi* Sahni, *Paranyctoides* cf. *P. sternbergi* Fox and named the taxa *Alphadon parapraesagus* Rigby and Wolberg, *Ectocentrocristatus foxi* Rigby and Wolberg, *Pediomyss fassetti* Rigby and Wolberg, *Aquiladelphus paraminor* Rigby and Wolberg, *Gypsonictops clemensi* Rigby and Wolberg and "*Cimolestes*" *lucasi* Rigby and Wolberg, all from the Fruitland Formation of the Fossil Forest (Quarry 1). There are no documented records of fossil mammals from the De-na-zin Member (Williamson and Weil, 2001), although the stratigraphic position of University of Arizona locality 8020 (Jon Powell Microsite) places it at the top of the Farmington Member (Flynn, 1986, fig. 2), just below the De-na-zin/Farmington member contact. If this placement is correct, then it indicates the apparent presence of *Mesodma formosa* (Marsh) in the upper Campanian. However, as Flynn (1986) noted, the specimen upon which this identification rests is small compared to Lancian specimens of this species, and that "this identification is a statement of probability." We therefore conclude that it does not pertain to *M. formosa*, but to some other taxon. The marsupial *Alphadon marshi* has also been identified from the same locality, but we note that genus is a common taxon throughout the Kirtlandian interval, and that the species identification may be in error.

Although mammals (*Alphadon marshi*, *Essonodon browni* Simpson, and *Mesodma formosa*) have been reported from the Ojo Alamo Formation (Naashoibito Member) (Clemens, 1973; Clemens et al., 1979; Flynn, 1986; Lehman, 1981, 1984, 1985a; Williamson and Weil, 2001), their biostratigraphic utility in determining a precise age for this unit is not certain. Clemens (1973) and Clemens et al. (1979) reported "*Alphadon* cf. *marshi*" from the Hunter Wash local fauna (now known to be early Kirtlandian), considered by them to be of "Edmontonian" age, so this would preclude this taxon from being an index species of the Lancian. *Essonodon?* sp. was listed by Armstrong-Ziegler (1978) as occurring in the Fruitland Formation, a new (unnamed) species similar to, but smaller than, *E. browni*, was also recovered from the Fruitland Formation (Flynn, 1986), and *E. browni* is known from the Naashoibito Member (Lehman, 1985a). However, in his revised faunal list for the Alamo Wash local fauna, Lehman (1985a, p. 72) cited this taxon as "*Essonodon* cf. *browni*," suggesting uncertainty in the species identification. The multituberculate *Mesodma formosa* was reported to occur in the Naashoibito Member based on two fragmentary teeth, (P_4 and M_1) by Flynn (1986), and in the Paleocene Nacimiento Formation by Sloan (1981). *Mesodma* cf. *M. formosa* was reported in the El Gallo Formation of Baja California del Norte, Mexico by Lillegraven (1972) and *Mesodma?* sp. was listed in the Fruitland by Armstrong-Ziegler (1978), suggesting that this taxon, at both the genus and species level, is not indicative of a precise age. It is clear that the relative age of the Naashoibito Member, based on the occurrence of the known assemblage of mammal species, remains equivocal, as stated by Flynn (1986).

Fossil mammals are poorly known for the upper Kirtland, and many

of the new taxa published by Flynn (1986) have not been formally named. Furthermore, the relationships of taxa reported by Rigby and Wolberg (1987), as well as those reported from the Kaiparowits Formation by Cifelli and Johanson (1994) and Eaton (2002) to those reported by Flynn (1986) are not known. Therefore, we refrain from considering any mammal species as index taxa of the Kirtlandian LVA.

Based on the analysis of the mammals from the Hunter Wash local fauna, Clemens (1973) noted its unique composition. He further questioned whether the dissimilarities (to the Lance and Judith River faunas) reflected temporal or ecologically-based, biogeographic differences and/or a combination of these factors (Clemens, 1973, p. 164). He stressed an inability to correlate the Hunter Wash local fauna to other faunas in the Rocky Mountain region because of inadequate data and/or poor biostratigraphic methodology. It now seems certain, based on our current understanding of the taxonomic composition of the Kirtlandian mammalian fauna, that it cannot be considered either of Judithian “age” (Cifelli et al., [2004] considered the Kirtlandian mammals to be Judithian, but they largely based this on the radioisotopic ages, not on the mammals themselves) or Edmontonian “age” and that the mammalian component, like the other vertebrates, is (in part) unique. This unique character of the Kirtlandian vertebrate fauna would be expected in a fauna that is temporally segregated and thus combines taxonomic aspects of both older (Judithian) and younger (Edmontonian) vertebrate faunas.

PALEOBIOGEOGRAPHIC IMPLICATIONS

Our understanding of the temporal position and taxonomic composition of the Kirtlandian vertebrate fauna has advanced considerably over the past decade and has profound implications for understanding its paleobiogeographic position with respect to the vertebrate faunas of the Judithian and Edmontonian LVAs. A number of papers have dealt with the correlation of the vertebrates from the Fruitland and Kirtland formations, most notably those of Russell (1975), Lucas et al. (1987), Lehman (1997, 2001) and Williamson (2000). However, in light of these new data the works of Lehman (1997, 2001) deserve special scrutiny, especially his idea that Late Cretaceous dinosaur distribution in the Western Interior exhibits endemism, and latitudinal and altitudinal zonation. Lately, there have been claims that endemism and provinciality has predominated the Late Cretaceous landscape in presentations by Gates (2004), Gates et al. (2005), Sampson et al. (2004), and Zanno et al. (2005). These, too, need to be critically assessed.

For many years, taxonomic differences between the Late Cretaceous vertebrate faunas of western North America have been largely regarded as a function of geography rather than of diachroneity (Sloan, 1970). Recently, a number of vertebrate faunas have been compared to the Kirtlandian fauna and to the classic Canadian faunas from the Oldman, Dinosaur Park (Judithian) and Horseshoe Canyon (Edmontonian) formations of Alberta. These include (from south to north): the vertebrate fauna of the Cerro del Pueblo Formation, Coahuila, Mexico (Rodríguez-De La Rosa and Cevallos-Ferriz, 1998; Kirkland et al., 2000b); Terlingua local fauna and Talley Mountain microsites, Big Bend Region, Texas (Rowe et al., 1992; Sankey, 2001; Sankey and Gose, 2001; Sankey, 2005), the Kaiparowits fauna of south-central Utah (McCord, 1997b, Eaton, 2002); the fauna from the Williams Fork Formation, western Colorado (Diem, 1999); and the “Mesaverde” Formation (mammals) of Wyoming (Lillegraven and McKenna, 1986). Most of these vertebrate faunas have been shoe-horned into the concept of the Judithian LVA, while noting that they contain a certain number of unique, or endemic, taxa. This view has been held by a number of workers who have tried to compare the Late Cretaceous vertebrate faunas of the north (Wyoming and northward) to those that occur farther south (Utah-Colorado and southward) (Lehman 1997, 2001). While some taxonomic endemism is likely, and should be considered, we believe that most of the taxonomic differences among these faunas have more to do with temporal position than with endemism or provinciality (see Fig. 5). We presented these data previously (Sullivan and Lucas, 2004), but detail

our argument here.

In an attempt to explain the taxonomic differences among the vertebrate faunas of the Judith River Group/Two Medicine Formation and those of the Fruitland/Kirtland and Aguja formations, Lehman (1997) recognized a “Late Campanian faunal provincialism” based largely on assumptions about distribution, abundance, rarity and identification of taxa and collecting biases. Lehman (1997) stated that dinosaurs were not cosmopolitan in distribution “in spite of their large body size and presumed high mobility” but instead argued that dinosaur genera and species were endemic to relatively small geographic areas during Judithian, Edmontonian and Lancian time (Fig. 6). This argument belies the evidence of the same or similar dinosaur taxa known from both Asia and North America during discrete temporal intervals, which suggests that some dinosaurs (i.e., *Saurolophus*, *Prenocephale*, *Edmontonia* and *Pachyrhinosaurus* [both known from the North Slope of Alaska and southern Alberta], *Nodocephalosaurus-Tarchia*) were far from endemic fixtures, incapable of movement or migration (e.g., Brown, 1913; Davies, 1987; Gangloff 1995, 1998; Gangloff et al., 2005; Maryańska and Osmólska, 1981; Morris, 1973; Sullivan, 1999, 2003).

Many of Lehman’s (1997) arguments were later reiterated by Lehman (2001), who stated that the Judithian LVA had the greatest hadrosaurid and ceratopsid diversity (genera and species). However, many taxa (e.g., *Brachylophosaurus* sp., *Hypacrosaurus stebingeri* Brown, new genus and species of lambeosaurine hadrosaur, new species of *Centrosaurus* and new genus and species of chasmosaurine ceratopsid) that occur in the older Oldman Formation (Eberth et al., 2001) are not known in the younger Dinosaur Park Formation, suggesting that these taxa are not contemporaneous with other hadrosaurids and ceratopsids known from the Judithian.

Lehman (1997) argued that the Late Cretaceous land-mammal “ages” of Russell (1975), and the Cenozoic “ages” established by the Wood committee (Wood et al., 1941) were “regional biostratigraphic units comparable to concurrent range zones” which had limited utility for biostratigraphic correlation. He concluded that the faunas derived from the Judith River Group/Two Medicine Formation, Fruitland/Kirtland formations, and Aguja Formation, were “broadly” Judithian in “age” and went on to state that the faunas of the Fruitland/Kirtland formations (and Aguja Formation, in part, of Texas) did not compare to the northern Judithian faunas because they contain “new endemic taxa” and lack age-diagnostic taxa.

Lehman (1997) thus advocated the recognition of two paleobiogeographic provinces: a northern (“*Corythosaurus*”) fauna; and a southern (“*Kritosaurus*”) fauna. He recognized “striking differences” in the faunas. Simply put, these included the presence of a taxon in one fauna and its absence/or rare occurrence in the other, and vice versa, as well as reversals in relative abundances of taxa among the three stratigraphic complexes (Judith River, Fruitland/Kirtland and Aguja). Lehman’s (1997) conclusion that the lower taxonomic diversity seen in the two southern faunas (Fruitland/ Kirtland and Aguja) is the result of sampling biases rather than representing a true decline in diversity, an observation with which we disagree. The differences in diversity are, in reality, due to the fact that the Judithian LVA is more than twice as long in duration (4.2 versus 2.0 my) as the Kirtlandian. We would thus expect to see more taxonomic diversity at both the genus and species level in the longer Judithian. Since Lehman’s (1997) paper has been published, the composition of the Fruitland/Kirtland faunas has been significantly revised. New discoveries include a new ankylosaurid, pachycephalosaurid, dromaeosaurid as well as a new undescribed species of centrosaurine and tyrannosaurid (see Table 1).

Lehman (1997) advocated the use of higher taxonomic categories (especially families) for assessing relative abundances. Not surprisingly, he noted that the relative abundance of “each family-level or larger group of dinosaurs is similar in all three areas (i.e., outcrops of the Judith River/Two Medicine, Fruitland/Kirtland and Aguja formations)” despite that fact that true diversity can only be realized at the smallest taxonomic level, which is the species (Sullivan, 1987, 2006c). Eaton and Kirkland (2003), in their study of diversity patterns of nonmarine Cretaceous vertebrates, also demonstrated that the greatest change in diversity is seen at the lower taxonomic levels.

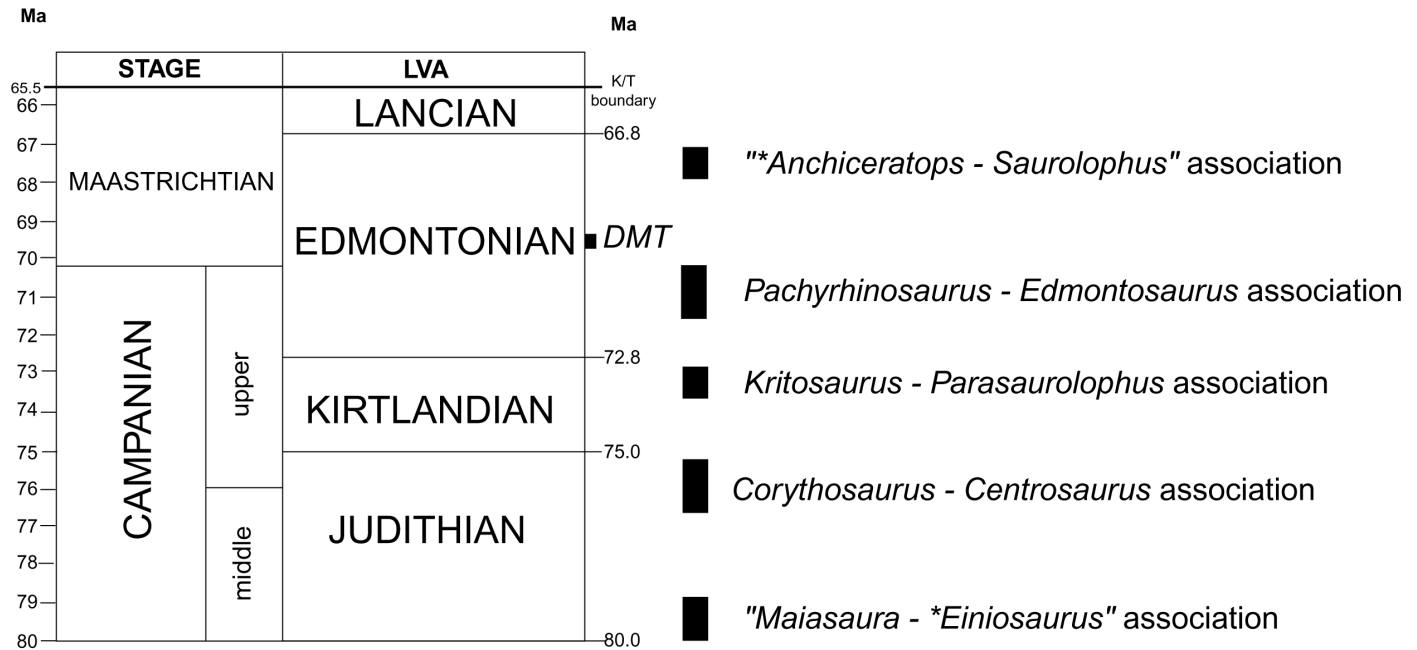


FIGURE 6. Stratigraphic positions of Lehman's (2001) "dinosaur associations" for the Judithian through Edmontonian (Lanciaan association not shown) demonstrating that these faunas are not coeval, thus undermining the concept of dinosaur faunal provincialism during the Late Cretaceous. **Einiosaurus* is not associated with *Maiasaura* (see discussion), rather it is from the Late Judithian and **Anchiceratops* is not associated with *Saurolophus*, rather it occurs below the DMT (Drumheller Marine Tongue) along with the ceratopsid *Pachyrhinosaurus* (see discussion).

Here, and elsewhere (Sullivan and Lucas, 2004), we challenge Lehman's (1997) assertions because he not only failed to discriminate the precise biochronology advocated here, but he also used higher taxonomic (family-level) similarities to arrive at his paleobiogeographic conclusions. Moreover, his correlation charts (Lehman, 1997, fig. 3) demonstrate that the Fruitland/Kirtland interval occupies the 74.8-72.8 Ma span of time, which is equivalent to his "Bearpaw time." We reject his conclusion that the Fruitland/Kirtland faunas (and others) "are all broadly equivalent" and note that his coarse biostratigraphy belies a more precise chronostratigraphic framework in which to characterize these vertebrate faunas. The so-called "northern" and "southern" vertebrate faunas are taxonomically different, not because they are provincial or endemic in nature, but rather because they are from different time intervals, so they represent different stages in evolutionary development. Lehman's paleobiogeography thus is largely an artifact of incorrect biochronology that assigned the Fruitland and Kirtland faunas a Judithian age.

Lehman (2001) presented three paleobiogeographic maps for the Late Cretaceous of the Western Interior and identified distinct dinosaur "associations" within the Judithian, Edmontonian and Lanciaan LVAs. These dinosaur associations formed the basis for recognizing supposedly distinct northern and southern faunas during the Late Cretaceous. The dinosaur associations for the Judithian are the: 1) *Maiasaura-Einiosaurus* association, 2) *Corythosaurus-Centrosaurus* association, and 3) *Kritosaurus-Parasaurolophus* association; for the Edmontonian, 1) *Kritosaurus-Parasaurolophus* association, 2) *Pachyrhinosaurus-Edmontosaurus* association and 3) *Anchiceratops-Saurolophus* association; and, for the Lanciaan, 1) *Alamosaurus-Quetzalcoatlus* association, 2) *Triceratops-Edmontosaurus* association and 3) *Leptoceratops-Triceratops* association. Each dinosaur association of the Judithian and Edmontonian, within its respective age, was considered coeval, which they are not. Biostratigraphically, none are contemporaneous, rather they are temporally distinct from each other (Fig. 6).

The *Maiasaura-Einiosaurus* association is a composite association. It doesn't exist unless one accepts that the ranges of the two taxa span the entire Judithian which they do not. *Maiasaura* is known solely from the

early Judithian, approximately 79-80 Ma based on radioisotopic dates published by Rogers et al. (1993), but it may actually pre-date the Judithian, which begins at around 79.1-80.0 Ma (Eberth, 2005; Eberth et al., 2001). Thus the occurrence of *Maiasaura* antedates the *Corythosaurus-Centrosaurus* association by a few million years. *Einiosaurus* is known solely from the upper Two Medicine Formation, approximately 45 m below the Bearpaw Formation. Thus, it is from the late Judithian (Sampson, 1995), moreover, it does not co-occur with *Maiasaura*. The *Corythosaurus-Centrosaurus* association was based on dinosaur taxa from the Dinosaur Park Formation, exclusive of the older Oldman and Foremost formations. Thus, this association dates between 76.5 and 74.2 Ma (Eberth et al., 2001).

The *Kritosaurus-Parasaurolophus* association is presented in both of Lehman's (2001) Judithian and Edmontonian paleobiogeographic maps, illustrating the transitional position of this vertebrate fauna, and thus supporting recognition of the unique temporal position of the Kirtlandian faunal assemblage. We note here that *Kritosaurus navajovius* and *Parasaurolophus tubicen* co-occur with certainty only in the upper part of the Kirtland Formation (De-na-zin Member), which is dated at 73.37-73.04 Ma based on the $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations published by Fassett and Steiner (1997).

The *Pachyrhinosaurus-Edmontosaurus* association comes from the lower part of the Horseshoe Canyon Formation (Unit 2), below the Drumheller Marine Tongue (DMT) and dates to approximately 70 Ma (D. Eberth, personal communication 2004). The "*Anchiceratops-Saurolophus* association," which in reality is another composite association from two distinct time intervals (*Anchiceratops* is a taxon found in association with *Pachyrhinosaurus* and *Edmontosaurus* and not with *Saurolophus*: Eberth et al., 2001), is from Unit 4 (the interval above the DMT) where the dinosaur taxa *Saurolophus*, *Parksosaurus* and *Hypacrosaurus* occur. This interval dates to approximately 68-67 Ma (Eberth et al., 2001).

Although not of major concern here, Lehman's Lanciaan paleobiogeographic scenario is equally misleading. The *Alamosaurus-Quetzalcoatlus* association is probably early Maastrichtian, based on recent work by Sullivan et al. (2005a,b) and is interpreted as coeval with part of the late Edmontonian. If so, this dinosaur association arguably may be,

in part, endemic based on the occurrence of the titanosaur *Alamosaurus*. However, given the biostratigraphic position of each of the aforementioned dinosaur associations, it seems likely that the *Alamosaurus-Quetzalcoatlus* association also occupies a temporally distinct interval of time that has been recently dated at $69 \text{ Ma} \pm 1.0$ (McDowell et al., 2004). This undermines any interpretation that considers these faunas as endemic and coeval, thus rendering the proposed Late Cretaceous dinosaur provincialism in the Western Interior indefensible.

We certainly agree that some background level of endemism existed and was probably present in all vertebrate faunal associations throughout the Mesozoic. However, based on detailed biostratigraphic evidence, coupled with radioisotopic dating, it is clear that these supposed Late Cretaceous dinosaur associations are first and foremost temporal entities. Moreover, there were no major geographic barriers, or major climatic regimes in the Western Interior, during the Late Cretaceous that would facilitate the partitioning of vertebrate faunas.

The “southern biome fauna” of Lehman’s (2001) late Judithian is, in fact, the vertebrate fauna of the Kirtlandian age. It is not a geographically endemic fauna, coeval with other Judithian vertebrate faunas elsewhere in the Western Interior. Instead, it is a temporally distinct fauna that can be correlated to other faunas outside the San Juan Basin. Moreover, it is becoming clear that these temporal vertebrate associations, based, in part, on local faunas, can be used to further subdivide the Judithian, Kirtlandian, Edmontonian and Lancian, thus allowing for a more highly resolved biostratigraphy and biochronology.

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APPENDIX-LIST OF HOLOTYPE OF UNIQUE KIRTLANDIAN TAXA AND PRINCIPAL REFERENCES

- Melivius chauliodous* (KUVF 88378): Wolberg and Hall (1989); Grande and Bemis (1998)
- Denazinemys nodosa* (USNM 8345) Kirtland Formation: (Gilmore, 1916)
- Denazinemys ornata* (USNM 13229) Kirtland Formation: (Gilmore, 1935)
- Boremys grandis* (USNM 12979) Kirtland Formation: Gilmore (1935)
- Neurankylus baueri* (USNM 8344) lower part of the Kirtland Formation: Gilmore (1916)
- Adocus bossi* (USNM 8613) lower part of the Kirtland Formation: Gilmore (1919)
- A. kirtlandius* (USNM 8593) lower part of the Kirtland Formation: Gilmore (1919)
- Thescelus hemispherica* (USNM 12818) Kirtland Formation: Gilmore (1935)
- "*Aspideretes*" *ovatus* (USNM 12986) Kirtland Formation: Gilmore (1935)
- "*Plastomenus*" *robustus* (USNM 8538) lower part of the Kirtland Formation: Gilmore (1919)
- Denazinosuchus kirtlandicus* (PMU R.232): Kirtland Formation: Wiman (1932); Sullivan and Lucas (2003)
- Saurornitholestes robustus* (SMP VP-1955) Kirtland Formation: Sullivan (2006)
- Anasazisaurus horneri* (BYU 12950) Kirtland Formation: Hunt and Lucas (1993); Williamson (2000)
- Kritosaurus navajovius* (AMNH 5799) Kirtland Formation: Brown (1910); Williamson (2000)
- Naashoibitosaurus ostromi* (NMMNH P-16106) Kirtland Formation: Hunt and Lucas (1993); Williamson (2000)
- Parasaurolophus cyrtocristatus* (FMNH P27393) Fruitland Formation: Ostrom (1961, 1963); Sullivan and Williamson (1999)
- P. tubicen* (PMU R.1250) Kirtland Formation: Wiman (1931); Sullivan and Williamson (1999)
- Nodocephalosaurus kirtlandensis* (SMP VP-900): Sullivan (1999); Sullivan (2006)
- Prenocephale goodwini* (NMMNH P-27403): (Williamson and Carr, 2002); Sullivan (2003)
- Pentaceratops sternbergii* (AMNH 6325) Fruitland Formation: Osborn (1923)

