



## ***The Kirtlandian, a new land-vertebrate "age" for the Late Cretaceous of western North America***

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# THE KIRTLANDIAN, A NEW LAND-VERTEBRATE “AGE” FOR THE LATE CRETACEOUS OF WESTERN NORTH AMERICA

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**ABSTRACT.**—The Kirtlandian is a new land-vertebrate “age” (LVA) representing 2.9 million years of Campanian time that fills a long-standing biochronologic gap between the Judithian and Edmontonian LVAs. This new LVA is characterized by the vertebrate fossil assemblages of the Fruitland and Kirtland formations, San Juan Basin, New Mexico, and the ceratopsine dinosaur *Pentaceratops sternbergii* is the principal index fossil. The Kirtlandian is defined as the time between the first appearance of *Pentaceratops sternbergii* (= end of the Judithian) and the first appearance of *Pachyrhinosaurus canadensis* (= beginning of the Edmontonian). Characteristic Kirtlandian vertebrates include: *Melivius chauliodous*, *Denazinosuchus kirtlandicus*, *Kritosaurus navajovius*, *Anasazisaurus horneri*, *Naashoibitosaurus ostromi*, *Parasaurolophus tubicen*, *P. cyrtocristatus*, *Nodocephalosaurus kirtlandensis*, and *Prenocephale goodwini*.

## INTRODUCTION

Russell (1975), in a classic paper, introduced, defined and applied to the Upper Cretaceous of North America five “stages” based on Cretaceous mammalian assemblages, a concept that was an outgrowth of the North American provincial “ages” established earlier by Wood et al. (1941) for the North American Tertiary terrestrial sequence. These provincial “ages” are biochronological units that derived their names from stratigraphic units that yield distinctive faunas, represent specific intervals of geologic time, and have been widely accepted and implemented by vertebrate paleontologists. But, unlike the Wood et al. (1941) committee’s provincial “ages,” which were intended to cover all of Tertiary time, Russell (1975) recognized that significant temporal gaps are present between some of his Cretaceous “ages.”

Here, we name one of these gaps the Kirtlandian land-vertebrate “age” (LVA). The Kirtlandian LVA is the interval of time between the Judithian and Edmontonian. It fills a gap in the North American Cretaceous LVA succession that spans some 2.9 million years, from 74.9 to 72.0 Ma (middle late Campanian), and can be characterized by a vertebrate fauna based on vertebrate fossil assemblages from the upper Fruitland and Kirtland formations in the San Juan Basin, New Mexico (Fig. 1).

## LITHOSTRATIGRAPHY

Understanding of the lithostratigraphy of the Fruitland and Kirtland formations (Fig. 2) began with Bauer (1916), and has most recently been summarized by Hunt and Lucas (1992, 2003). Bauer (1916) named the Fruitland and Kirtland formations, and he divided the Kirtland into three members: 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 (2000), we now place the Naashoibito Member back in the Ojo Alamo Formation.

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 Picture Cliffs Sandstone, a regressive marine shoreline deposit (Fassett and Hinds, 1971) (Fig. 2). It consists of two members, a lower coal-bearing Neh-nah-ne-zad Member and an upper Fossil Forest Member (Hunt and Lucas, 2003). The boundary between the Fruitland and overlying Kirtland Formation is gradational and conformable, and it is placed at the top of the highest, laterally persistent coal bed or at the base of a distinctive, ferruginous sandstone.

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) (Fig. 2). The top of the Kirtland Formation is marked by a distinct unconformity, overlain locally by the lower conglomerate of the Ojo Alamo Formation. We now recognize three members of the Kirtland Formation: Hunter Wash, Farmington, and De-na-zin members, 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 (HWlf) and the Willow Wash local fauna (WWlf), collectively characterize the Kirtlandian LVA. Clemens (1973, p. 165) defined the HWlf 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 (Figs. 1-2). Therefore, we regard this interval, and its correlatives, as the upper Fruitland/lower Kirtland undifferentiated. Clemens (1973) reviewed some of the taxa from this interval, which include vertebrate fossils reported by Gilmore (1916, 1919, 1935).

Williamson and Sullivan (1998) named the WWlf for fossil vertebrates from the De-na-zin Member of the Kirtland Formation. Many of the vertebrate taxa of the WWlf were formerly

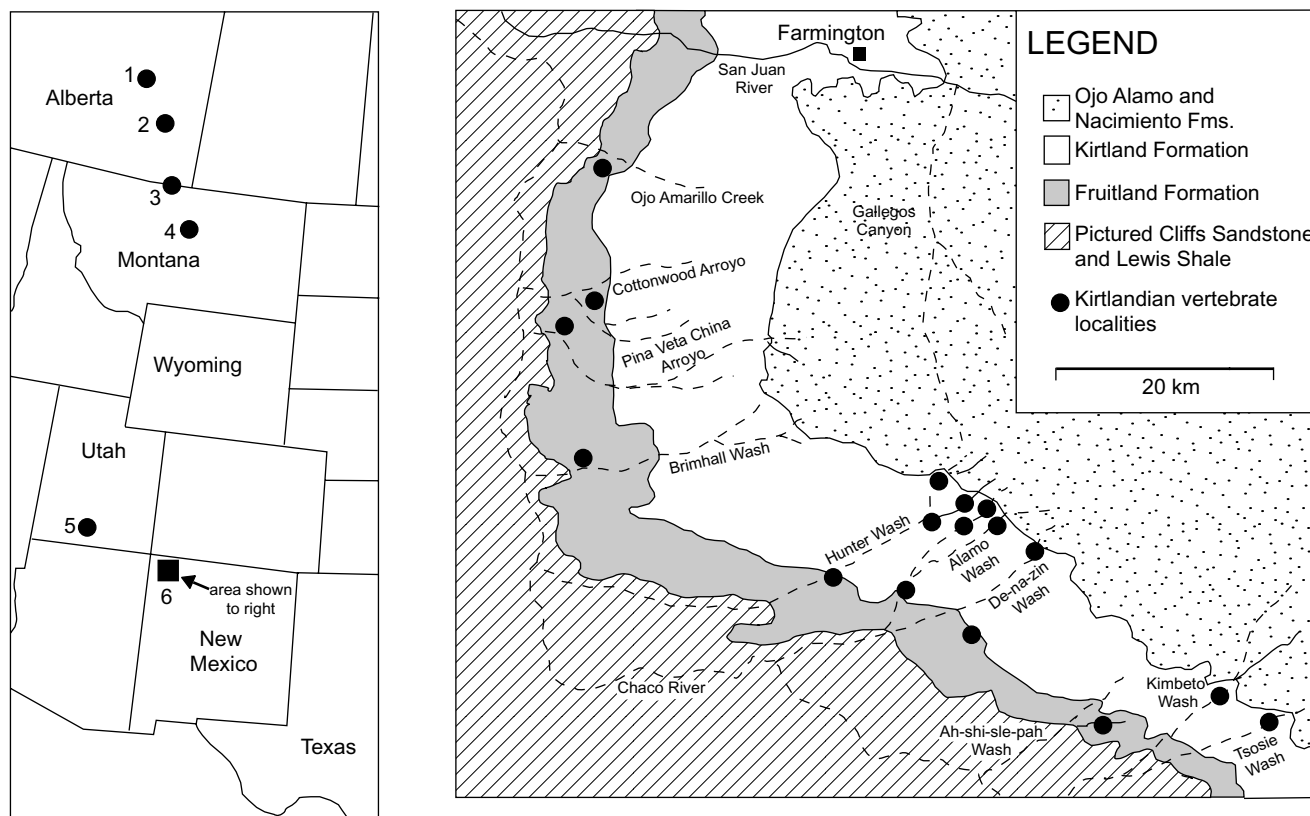


FIGURE 1. Location map (left) of late Campanian/early Maastrichtian dinosaur-bearing units in western North America. 1. Horseshoe Canyon and Bearpaw formations, Alberta; 2. Dinosaur Park and Oldman formations, Alberta; 3. Milk River Formation, Alberta; 4. Bearpaw, Two Medicine and Judith River formations, Montana; 5. Kaiparowits Formation, Utah; and 6. Fruitland and Kirtland Formations, New Mexico. Map (right) of part of the west-central San Juan Basin, New Mexico, showing the principal dinosaur collecting areas of Kirtlandian age.

considered part of the Alamo Wash local fauna (Lehman, 1981) of the Naashoibito Member (Ojo Alamo Formation) but have subsequently been documented as originating from the De-na-zin Member of the Kirtland Formation. Comparison of key taxa from the HWlf and WWlf shows striking similarity (Table 1), so we summarize the combined local faunas, which collectively characterize the Kirtlandian LVA.

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). Only the recently named actinopterygian *Melivius chauliodous* (Hall and Wolberg, 1989; Grande and Bemis, 1998) is a potential Kirtlandian index taxon.

Amphibians: Armstrong-Ziegler (1980) reported a few amphibian from the upper Fruitland Formation, but we regard the identifications of these fragmentary fossils, many of which have been assigned to Lancian or younger (Paleocene) taxa, as suspect.

Turtles: Hay (1908) and Gilmore (1916, 1919, 1935) named a variety of Fruitland-Kirtland turtles based on nearly complete shells (carapaces and plastra). Gaffney (1972) synonymized several species, but we favor resurrecting some taxa based on the presence of taxonomically useful characters recognized by the original authors. We thus recognize five species of baenid turtles: "*Baena*" *nodosa*, "*Baena*" *ornata*, *Boremys grandis*, *Neurankylus baueri*, *Thescelus hemispherica*; two dematemydids: *Adocus bossi* and *A.*

*kirtlandicus*; one nanhsiungchelyidid: *Basilemys nobilis*; and two trionychids: *Aspideretes ovatus* and *Plastomenus robustus* (Gilmore, 1916, 1919, 1935). E. Gaffney (pers. commun., 2003) will be naming a new bothremydid genus from the Hunter Wash Member.

Sauria: A few lizards, and one snake, have been reported from the Fruitland Formation by Armstrong-Ziegler (1978; 1980). 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). The aniliid snake *Coniophis cosgriffi* is known from a single specimen whose diagnosis is inadequate (Rage, 1984). In addition, many of Armstrong-Ziegler's fossil lizard identifications are incorrect, including cf. *Gerrhonotus* sp. (Good, 1988) and *Leptochamops denticulatus* (Gao and Fox, 1996). Fossil saurians are not now well documented from the Fruitland-Kirtland formations or helpful for correlation.

Crocodylia: One "mesosuchian," *Denazinosuchus* (= *Goniopholis*) *kirtlandicus*, and two crocodylids (*Brachychampsia montana* and *Leidyosuchus* sp.) have been reported from the Fruitland and Kirtland formations (Armstrong-Ziegler, 1980; Lucas, 1992; Lucas and Sullivan, 2003; Sullivan and Lucas, in press; Wiman, 1932). 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. Recent documentation of *B. montana* in

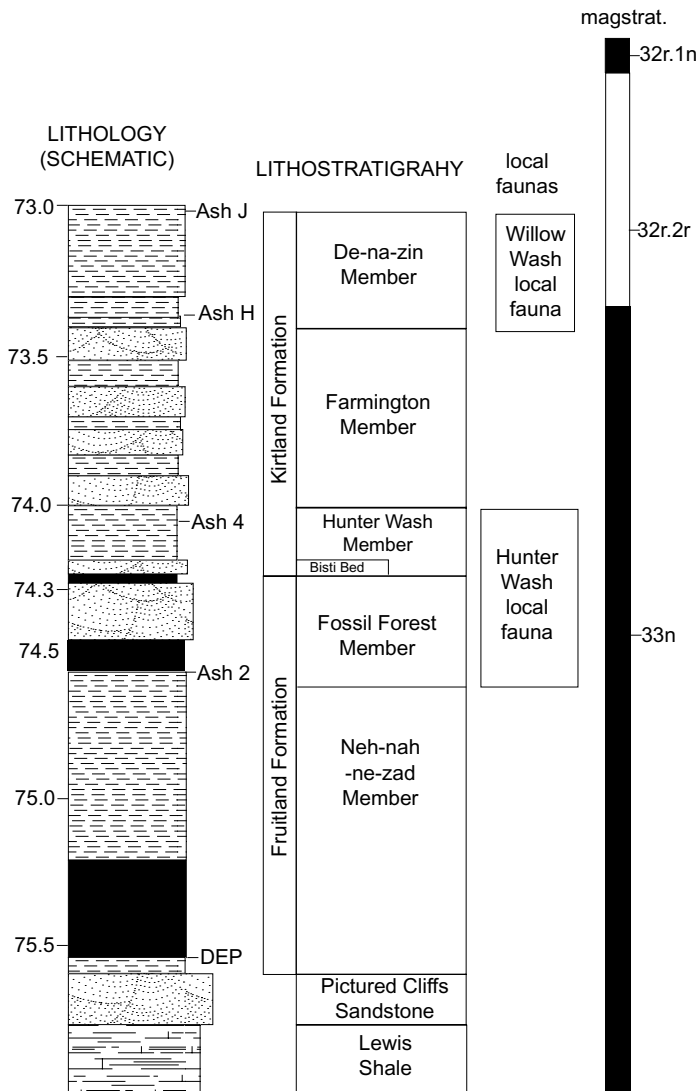


FIGURE 2. Generalized stratigraphic section of the upper Fruitland and Kirtland formations, San Juan Basin, New Mexico.

the Menefee Formation and De-na-zin Member of the Kirtland Formation establishes a long stratigraphic range for this species, previously known also from Lancian age strata, so it cannot be used as an index taxon (Sullivan and Lucas, in press). Only the "mesosuchian" *Denazinosuchus kirtlandicus* is a potential crocodylian index taxon of the Kirtlandian.

**Dinosauria — Tyrannosauridae:** Several tyrannosaur/carnosaur genera have been cited as coming from the Fruitland and Kirtland formations, but Carr and Williamson (2000) determined that the only diagnostic carnosaur is *Daspletosaurus* sp. They also 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*. Recently, T. Carr (personal communication, 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.

**Ornithomimidae:** Only one diagnostic ornithomimid specimen, identified as *Ornithomimus antiquus*, is known from the Kirtland Formation (Sullivan, 1997). Previous reports of cf. *Ornithomimus* sp. and *Struthiomimus* sp. from the Fruitland and Kirtland formations, respectively, are less certain (Hunt and Lucas, 1992).

**Dromaeosauridae:** Sullivan and Lucas (2000b) documented a left frontal of the dromaeosaurid *Saurornitholestes langstoni* from the De-na-zin Member of the Kirtland Formation. Three isolated teeth of *S. langstoni* have been reported from the Fruitland Formation of the Fossil Forest area (Hall, 1991), but we have not been able to verify their taxonomic identity. Isolated, indeterminate dromaeosaur teeth were previously reported from both the Fruitland and Kirtland formations (Armstrong-Zeigler, 1980; Lucas et al. 1987).

**Theopoda — incertae sedis:** A single non-serrated tooth, with wrinkled enamel, recovered from the De-na-zin Member of the Kirtland Formation, is identified as cf. *Paronychodon lacustris*. It is identical to those recovered from the Milk River Formation of Alberta (Baszio, 1997, pl. 6, figs. 81, 82).

**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* (Sullivan and Lucas, 2000a). We are not certain that these sauropod caudal vertebrae represent the same taxon as those that have been referred to *A. sanjuanensis* from younger strata (i.e., Naashoibito Member of the Ojo Alamo Formation, New Mexico; North Horn Formation, Utah; Javelina/Black Peaks formations, Texas).

**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.

**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; 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*. In addition, 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*. Mere sympatry of the two species, which has not yet 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. *P. cyrtocristatus* may also be a key 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/Ankylosauridae:** Nodosaurids and ankylosaurids have been reported from the Fruitland and Kirtland forma-

TABLE 1. The distribution and identity of the vertebrate megafauna from the Fruitland and Kirtland formations used for defining the Kirtlandian LVA. Only valid taxa, identifiable to species, are considered. HWlf = Hunter Wash local fauna; WWlf = Willow Wash local fauna. See text for discussion of taxa.

TAXON GROUP	SUB GROUP	GENUS	SPECIES	HWlf	WWlf
<b>Actinopterygii</b>	Amiidae	<i>Melivius</i>	<i>chauliodous</i>	X	X
<b>Testudines</b>	Bothremydidae	Bothremydidae, n. gen.	<i>barberi</i>	X	
	Baenidae	" <i>Baena</i> "	<i>ornata</i>	X	
		" <i>Baena</i> "	<i>nodosa</i>	X	X
		<i>Boremys</i>	<i>grandis</i>	X	
		<i>Neurankylus</i>	<i>baueri</i>	X	X
		<i>Thescelus</i>	<i>hemispherica</i>	X	X
	Dermatemydidae	<i>Adocus</i>	<i>bossi</i>	X	
		<i>Adocus</i>	<i>kirtlandius</i>	X	
	Nanhsiungchelyidae	<i>Basilemys</i>	<i>nobilis</i>	X	X
	Trionychidae	<i>Aspideretes</i>	<i>ovatus</i>	X	
		<i>Plastomenus</i>	<i>robustus</i>	X	X
<b>Crocodylia</b>	"Mesosuchia"	<i>Denazinosuchus</i>	<i>kirtlandicus</i>		X
	Crocodylidae	<i>Brachychampsia</i>	<i>montana</i>	X	X
<b>Dinosauria</b>	Tyrannosauridae	Tyrannosauridae, n. gen.	n. sp.	X	
	Ornithomimidae	<i>Ornithomimus</i>	<i>antiquus</i>		X
	Dromaeosauridae	<i>Sauornitholestes</i>	<i>langstoni</i>	X	X
	Titanosauridae	<i>Alamosaurus</i>	<i>sanjuanensis</i>		X
	Hadrosauridae	<i>Anasazisaurus</i>	<i>horneri</i>	X	
		<i>Kritosaurus</i>	<i>navajovius</i>	X	X
		<i>Naashoibitosaurus</i>	<i>ostromi</i>		X
		<i>Parasaurolophus</i>	<i>cryptocris-tatus</i>	X	
		<i>Parasaurolophus</i>	<i>tubicen</i>		X
	Ankylosauridae	<i>Nodocephalosaurus</i>	<i>kirtlandensis</i>	?	X
	Pachycephalosau- ridae	<i>Prenocephale</i>	<i>goodwini</i>	?	X
	Neoceratopsidae	<i>Pentaceratops</i>	<i>sternbergii</i>	X	X

tions based largely on isolated dermal plates and limb bones. The nodosaurid *?Panoplosaurus* and ankylosaurid *?Euoplocephalus* were based on a left scapula and right humerus, respectively (Lucas et al., 1987). The only diagnostic ankylosaurian is the ankylosaurid *Nodocephalosaurus kirtlandensis* from the De-na-zin Member (Sullivan, 1999), and it is unique to the Kirtland Formation and thus may be an index taxon of the Kirtlandian. Isolated osteoderms, similar to those on the holotype skull, have recently been recovered from the Hunter Wash Member. We note that *Edmontonia australis*, named by Ford (2000), based on a pair of medial cervical scutes (osteoderms), is not diagnostic to species, so it is a *nomen dubium*. In addition, *Glyptodontopelta mimus*, also named by Ford (2000), based on a section of pelvic osteoderms, supposedly from the Naashoibito Member (but may

have come from the De-na-zin Member), is a *nomen dubium* for the same reason.

Pachycephalosauridae: Only a few pachycephalosaur specimens are known from the Fruitland and Kirtland formations. Williamson and Carr (2003) named "*Sphaerolithus*" *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 *Sphaerolithus* 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.

Neoceratopsidae: The ceratopsine *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. A few specimens are also known from the De-na-zin Member. *P. sternbergii* is present throughout the entire Fruitland-Kirtland stratigraphic interval and thus serves as the principal index taxon of the Kirtlandian.

Mammals: 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 HWlf. These included the following multituberculates: an indeterminate “plagiaulacoid,” *Paracimexomys judithae*, *P. n. sp.*, cf. *Mesodma senecta*, *M. n. sp.* or *Cimexomys* cf. *C. antiquus*, cf. *Kimbetohia campi*, *Cimolodon electus*, *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. *Pediomys cooki*; and the eutherians *Gypsonictops* n. sp. and cf. *Cimolestes* sp.

Rigby and Wolberg (1987) recognized *Alphadon halleyi*, cf. *Eodelphis* sp., *Gypsonictops* cf. (*G.*) *lewisi*, *Paranyctoides* cf. *P. sternbergi* and named the taxa *Alphadon parpraesagus*, *Ecto-centrocristatus foxi*, *Pediomys fassetti*, *Aquiladelphus paraminor*, *Gypsonictops clemensi* and “*Cimolestes*” *lucasi*, 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* 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 didelphid *Alphadon marshi* has also been identified from the same locality, but we note that that genus is a common taxon throughout the Kirtlandian interval and that the species identification may be in error.

Because fossil mammals are poorly known for the upper Kirtland, and many of the new taxa published by Flynn (1986) have not been formally named, and the relationships of taxa reported by Rigby and Wolberg (1987) to those reported by Flynn (1986) are not known, we refrain from considering any mammal species as index taxa of the Kirtlandian.

## GEOCHRONOMETRY

Fassett and Steiner (1997) recently published a series of Ar/Ar ages on Fruitland-Kirtland ash beds undertaken by J. Obradovich. These ages provide very precise age control for the Fruitland-Kirtland succession (Figs. 2-3).

The base of the Fruitland Formation lies slightly below ash DEP (Dog Eye Pond), which has been dated at  $75.56 \pm 0.41$  Ma. The Fruitland-Kirtland contact lies between Ash 2, dated at  $74.55 \pm 0.29$  Ma, and Ash 4, dated at  $74.11 \pm 0.62$  Ma, which lies on top

of a persistent coal bed. 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  $73.37 \pm 0.28$  Ma and Ash J, dated at  $73.04 \pm 0.25$  Ma.

## MAGNETOCHRONOLOGY

Radioisotopic ages and biostratigraphy securely place the Fruitland-Kirtland interval in the Campanian, so Maastrichtian age assignments based on magnetic-polarity stratigraphy (e.g. Lindsay et al., 1981) are untenable. 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-normal-reversed polarity upper Kirtland Formation is correctly assigned to chrons 32r.2r, 32r.1n, and 32r.1r (Fassett and Steiner, 1997; Lerbekmo and Braman, 2002). Therefore, the Kirtlandian encompasses the younger part of chron 33n, all of chrons 32r.2r and 32r.1n and the older part of chron 32r.1r (Fig. 3).

## KIRTLANDIAN LVA DEFINED

We introduce the Kirtlandian LVA as the time interval between the end of the Judithian and the beginning of the Edmontonian. The first appearance of *Pentaceratops sternbergii* defines the beginning of the Kirtlandian (and end of the Judithian). The first appearance of *Pachyrhinosaurus canadensis* defines the beginning of the Edmontonian (and end of the Kirtlandian).

The Kirtlandian is the interval unit of time between the Judithian and Edmontonian, and represents approximately 2.9 million years, from 74.9 Ma to 72 Ma, and coincides with the upper part of magnetopolarity chron 33n and the lower part of magnetopolarity chron 32r (Fig. 3).

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, USA. The characteristic Kirtlandian fauna is a composite of both the Hunter Wash local fauna and the Willow Wash local fauna.

Principal correlatives: Lower part of the Bearpaw Formation of Montana, USA and Alberta, Canada and the Kaiparowits Formation of Utah, USA (see discussion below).

Principal index fossil: *Pentaceratops sternbergii* Osborn, 1923. We have chosen *P. sternbergii* as the principal index fossil for the Kirtlandian because it is restricted to and found throughout the entire Kirtlandian interval and is a well documented taxon. We note that some other taxa, notably *Nodocephalosaurus kirtlandensis*, both species of *Parasaurolophus*, and possibly *Kritosaurus*, are potential index fossils.

First appearance: *Melivius chauliodous*, “*Baena*” *ornata*, “*Baena*” *nodosa*, *Boremys grandis*, *Neurankylus baueri*, *Thescelus hemispherica*, *Adocus bossi*, *A. kirtlandicus*, *Basilemys nobilis*, *Aspideretes ovatus*, *Plastomenus robustus*, *Parasaurolophus cyrtocristatus*, and *Pentaceratops sternbergii*.

Last appearance: *Melivius chauliodous*, “*Baena*” *nodosa*, *Neurankylus baueri*, *Thescelus hemispherica*, *Basilemys nobilis*, *Denazinosuchus kirtlandicus*, *Saurornitholestes langstoni*, *Kritosaurus navajovius*, *Naashoibitosaurus ostromi*, *Parasaurolophus*

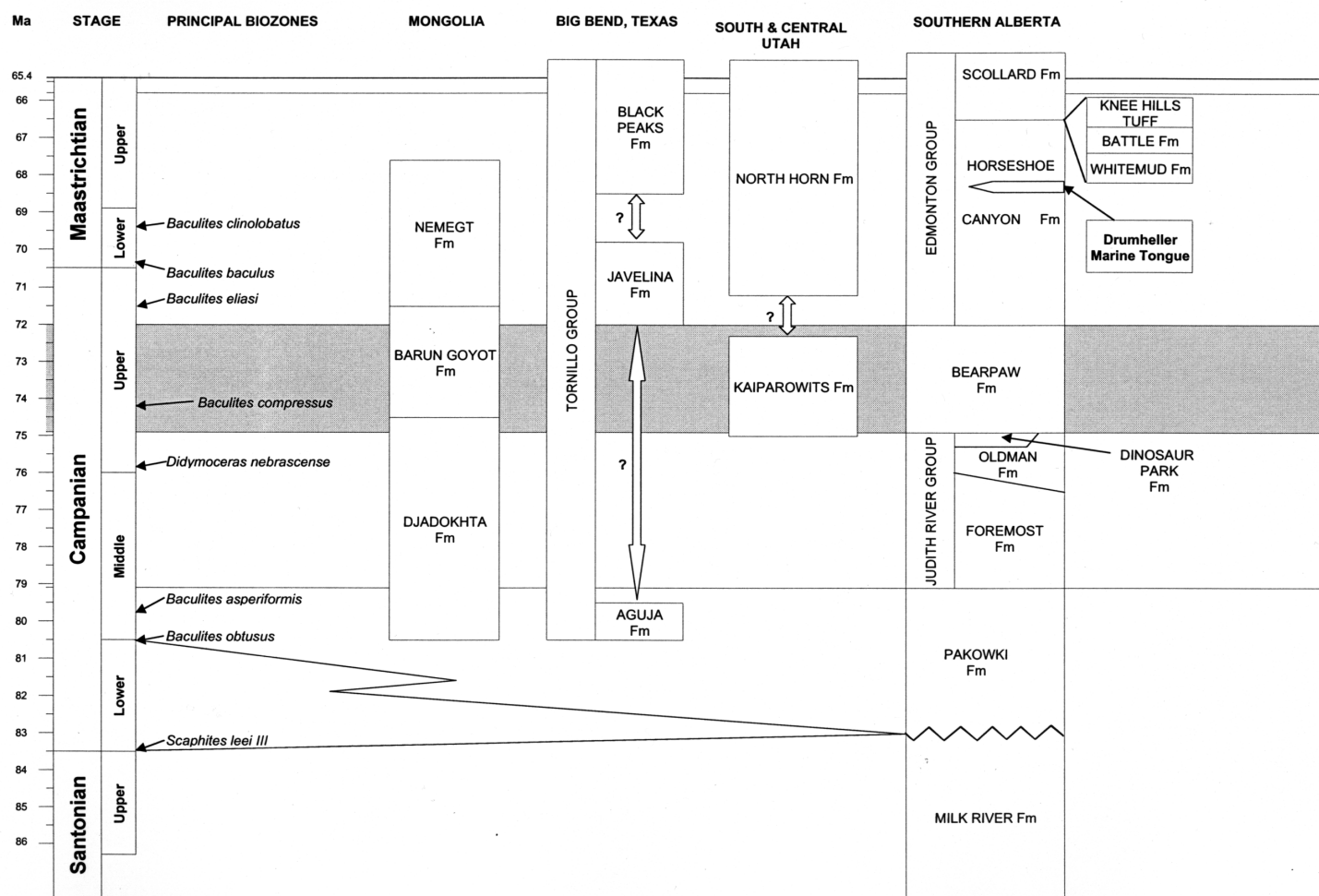


FIGURE 3. Correlation of the Kirtlandian LVA to other North American Upper Cretaceous sections and ages (modified from Sullivan, 2003). Correlation data based on Eberth et al. (2001), Fassett and Steiner (1997), Lerbekmo and Braman (2002), and Obradovich (1993).

*tubicen*, *Nodocephalosaurus kirtlandensis*, *Prenocephale goodwini*, and *Pentaceratops sternbergii*.

### CORRELATION

Outside of the San Juan Basin, two North American stratigraphic units are considered to be of Kirtlandian age: the terrestrial rocks of the Kaiparowits Formation, south-central Utah, and the marine strata of the lower part of the Bearpaw Formation, Montana-Alberta (Fig. 1).

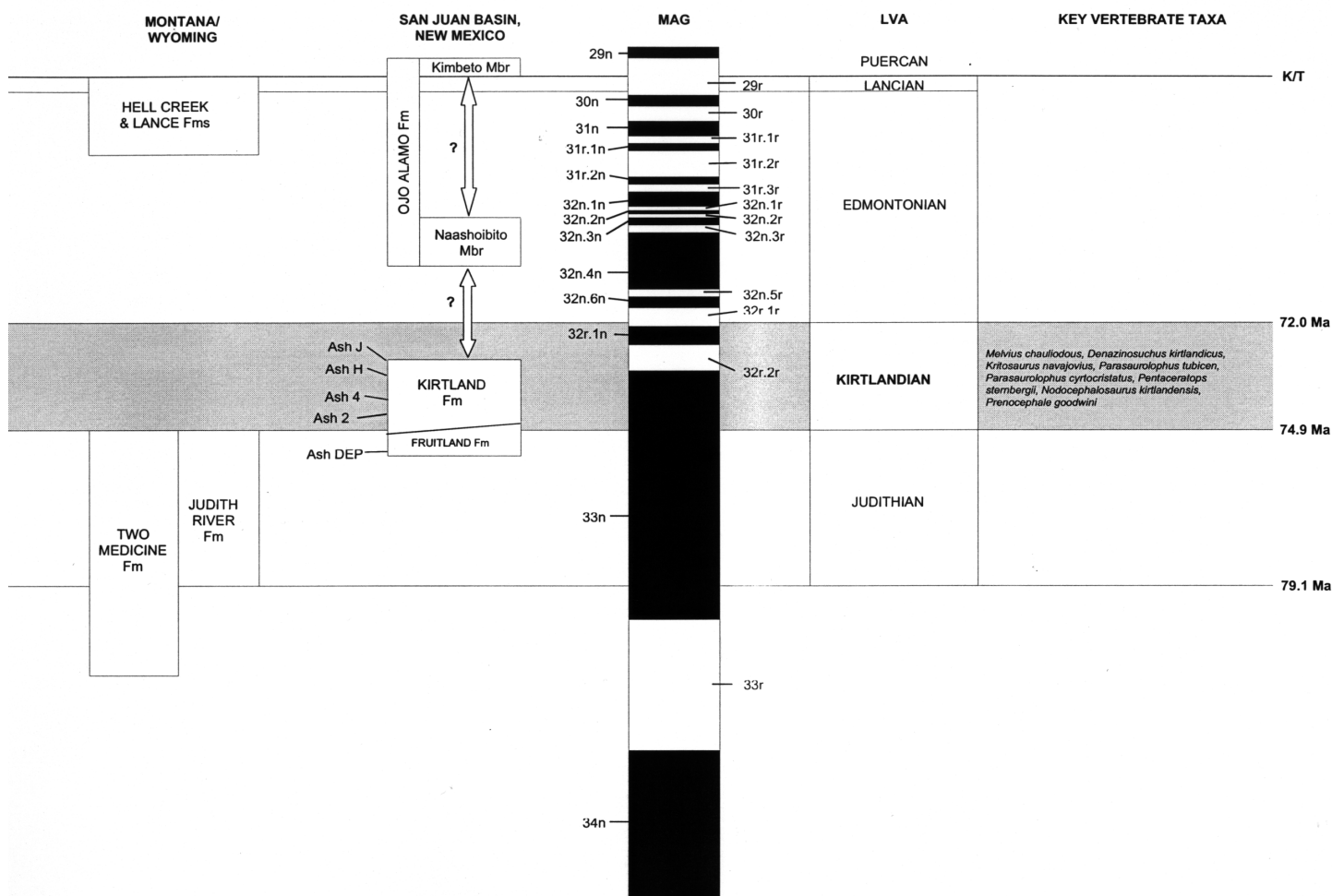
Eaton et al. (1999) documented the fossil vertebrates from the Kaiparowits Formation and assigned it a Campanian age based on analysis of palynomorphs and lack of Maastrichtian age mammals. They recognized the first occurrences of the "insectivore" *Gypsonictops* sp. and the turtle *Boremys* sp. in the Kaiparowits, and cited the former taxon as an index fossil, assigning it of Judithian age (Eaton et al., 1999). In addition, they noted the turtle *Compsemys* sp. is a common element, and its presence in the Fruitland Formation has been listed by Hunt and Lucas (1992). Most of the taxa listed by Eaton et al. (1999) are not identified to the specific level. Moreover, a number of the Kaiparowits lower vertebrates,

especially amphibians and lizards (squamates), were referred to Lancian and younger (Tertiary) taxa, which we consider suspect. In addition, Eaton et al., (1999) recognized that the multituberculates from the Kaiparowits Formation "do not compare well to any fauna and include many new forms." The only unequivocal index fossil is the lambeosaurine *Parasaurolophus cyrtocristatus*, known from two specimens from the Kaiparowits Formation and one from the Fruitland/Kirtland (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 Kirtland formations (Fig. 3).

Horner (1979) reported on a small terrestrial vertebrate fauna from the marine Bearpaw (Shale) Formation of south-central Montana. Among the vertebrates is a hadrosaurine partial skull and postcranial skeleton that he concluded is "nearly identical with the holotype" of *Gryposaurus* (*Kritosaurus*) *notabilis* (Horner, 1979), referring it to "*Hadrosaurus notabilis*." The genus *Kritosaurus* (*Gryposaurus*) is consistent with a Kirtlandian age, but both *Gryposaurus notabilis* and "*Kritosaurus incurvimanus*" are also known from the Dinosaur Park Formation (Eberth et al., 2001), which is slightly older than the beginning of the Kirtland-



# THE KIRTLANDIAN, A NEW LAND-VERTEBRATE “AGE” FOR THE LATE CRETACEOUS



ian (Fig. 3). 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. The base of the Bearpaw Formation lies just below the *Baculites compressus* ammonite biozone (dated at  $73.35 \pm 0.35$  Ma by Obradovich, 1993) whereas an ash in the lowermost part of the Bearpaw Formation has been dated at 74.9 Ma (Eberth et al., 2001). The top of the Bearpaw Formation, and base of the Horseshoe Canyon Formation (= beginning of the Edmontonian) coincides with the chron 32n-32r boundary dated at 72 Ma (Eberth et al., 2001, Lerbekmo and Braman, 2002).

The Ne-nah-ne-zad Member of the Fruitland Formation is approximately correlative to the Dinosaur Park Formation and upper parts of the Two Medicine and Judith River formations, whereas the Fossil Forest Member of the Fruitland and the lowest part of the Kirtland (Hunter Wash Member, in part) straddle the Judithian-Kirtlandian boundary, slightly overlapping the uppermost parts of the Dinosaur Park and Oldman formations in Alberta and the Two Medicine and Judith River formations in Montana/Wyoming by about 0.2 my (Fig. 3). The Kirtland

Formation is correlative with the lower two thirds of the Bearpaw Formation. The bulk of the time represented by the upper Fruitland-Kirtland sequence is at least 2.2 million years. Thus, the Kirtlandian vertebrates occupy a time interval distinct from the Judithian and Edmontonian as defined by Russell (1975).

## KIRTLANDIAN PALEOBIOGEOGRAPHY

Lehman (1997), in a paper on late Campanian dinosaur paleobiogeography, suggested that the LVAs of Russell (1975) and those established by the Wood committee (Wood et al., 1941) had limited utility for biostratigraphic correlation because of their regional nature. He stated that the Fruitland/Kirtland (and Aguja of Texas) did not compare to the northern Judithian faunas because they were known by “new endemic taxa” and lacked diagnostic taxa. We challenge Lehman’s (1997) assertions because he not only failed to discriminate finer units of geologic time, but 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 74.2-72 Ma span of time, which is, in part, 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, contrary to scenarios presented by Lehman (1997, 2001).

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Coquina bed of unionid (freshwater) bivalves in the Upper Triassic Sonsela Member of the Petrified Forest Formation, Zuni Mountains.