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DISTRIBUTION, AGE AND CORRELATION OF CRETACEOUS FOSSIL VERTEBRATES FROM ARIZONA

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Abstract—Fossil vertebrates of Cretaceous age are known from two principal areas in Arizona—the Lower and Upper Cretaceous strata of the Basin and Range of southeastern Arizona and the Upper Cretaceous strata of the Black Mesa Basin on the Colorado Plateau in northeastern Arizona. Cretaceous fossil vertebrates, especially dinosaurs, from southeastern Arizona can be summarized as encompassing largely isolated records, mostly from Lower Cretaceous strata, and a single diverse assemblage from one Upper Cretaceous collecting area. These fossils can be assigned to two temporal intervals: (1) Albian records from the upper part of the Bisbee Group in the Empire, Whetstone and Mule Mountains, including the ornithopod "*Tenontosaurus*" and the sauropod *Sonorasaurus thompsoni* Ratkevich; and (2) Campanian records, including titanosaurs, hadrosaurs, ceratopsians, dromaeosaurs, and tyrannosaurs from the Fort Crittenden Formation in the Santa Rita Mountains, and the "Tucson Mountains dinosaur," a hadrosaur from the Tucson Mountains. In the Black Mesa basin of northeastern Arizona, late Cenomanian- middle Turonian records of vertebrate fossils are mostly of selachian teeth but include a few records of marine turtles, crocodilians, plesiosaurs and mosasaurs.

Keywords: Arizona, Cretaceous, dinosaur, chondrichthyan, Judithian, Cashenranchian, sauropod, Cenomanian, Campanian, Albian

INTRODUCTION

Cretaceous strata in Arizona contain a diffuse but significant record of fossil vertebrates (Fig. 1). These are fossils of nonmarine vertebrates (mostly dinosaurs) of Early and Late Cretaceous age from southeastern Arizona, and fossils of marine vertebrates of Late Cretaceous age from northeastern Arizona. Here, we review the distribution and correlation of Cretaceous vertebrate localities in Arizona. In this paper, UALP = University of Arizona Laboratory of Paleontology, Department of Geosciences, Tucson.

SOUTHEASTERN ARIZONA

Stratigraphic Setting

Cretaceous strata preserved in southeastern Arizona were deposited in two different tectonic regimes. The older Cretaceous rocks belong to the Bisbee Group and were deposited in rift basins that were part of a large extensional tectonic region that encompassed parts of northern Mexico (Sonora and Chihuahua), southwestern New Mexico and southeastern Arizona; the younger Cretaceous rocks were deposited during compressional tectonism of the Laramide orogeny (Dickinson and Lawton, 2001, and references cited therein). Between the Bisbee Group and Laramide Cretaceous deposits there is a regional unconformity during which little or no sediment accumulated in southeastern Arizona (e.g., Hayes, 1970b). The age of Bisbee Group strata in southeastern Arizona ranges from Jurassic to late Albian, and perhaps locally into the Cenomanian; Laramide strata in southeastern Arizona are Campanian-Paleogene in age (e.g., Hayes, 1970b; Hayes and Drewes, 1978; Dickinson and Lawton, 2001).

Age and Correlation

Published reviews of southeastern Arizona's Cretaceous vertebrates include Miller (1964), McCord and Tegowski (1996), Ratkevich (1997) and Heckert et al. (2003). Here, we review the age assignments of these occurrences (Fig. 2).

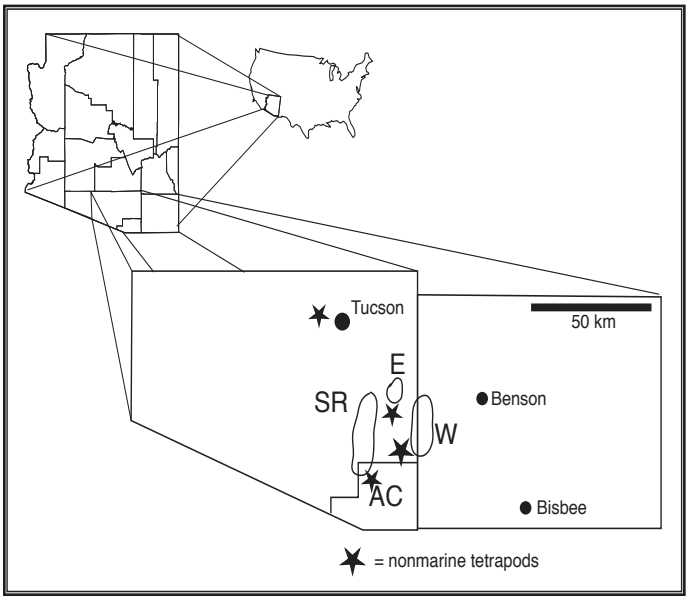

FIGURE 1. Index map of Arizona showing the location of Cretaceous vertebrate fossil localities in southern Arizona. AC = Adobe Canyon, E = Empire Mountains, M = Mule Mountains, T = Tucson Mountains; W = Whetstone Mountains.

Empire Mountains

An "iguanodontid" femur (Fig. 2A-C) from the Empire Mountains (Moore and Miller, 1960; Miller, 1964) is from the Shellenberger Canyon Formation and was referred to *Tenontosaurus* by Galton and Jensen (1979), but we identify it as cf. *Tenontosaurus*. Cranwell (2001) also reported turtle, crocodilian, nodosaur and sauropod remains from this interval south of the Empire Mountains. The Shellenberger Canyon Formation is homotaxial with the

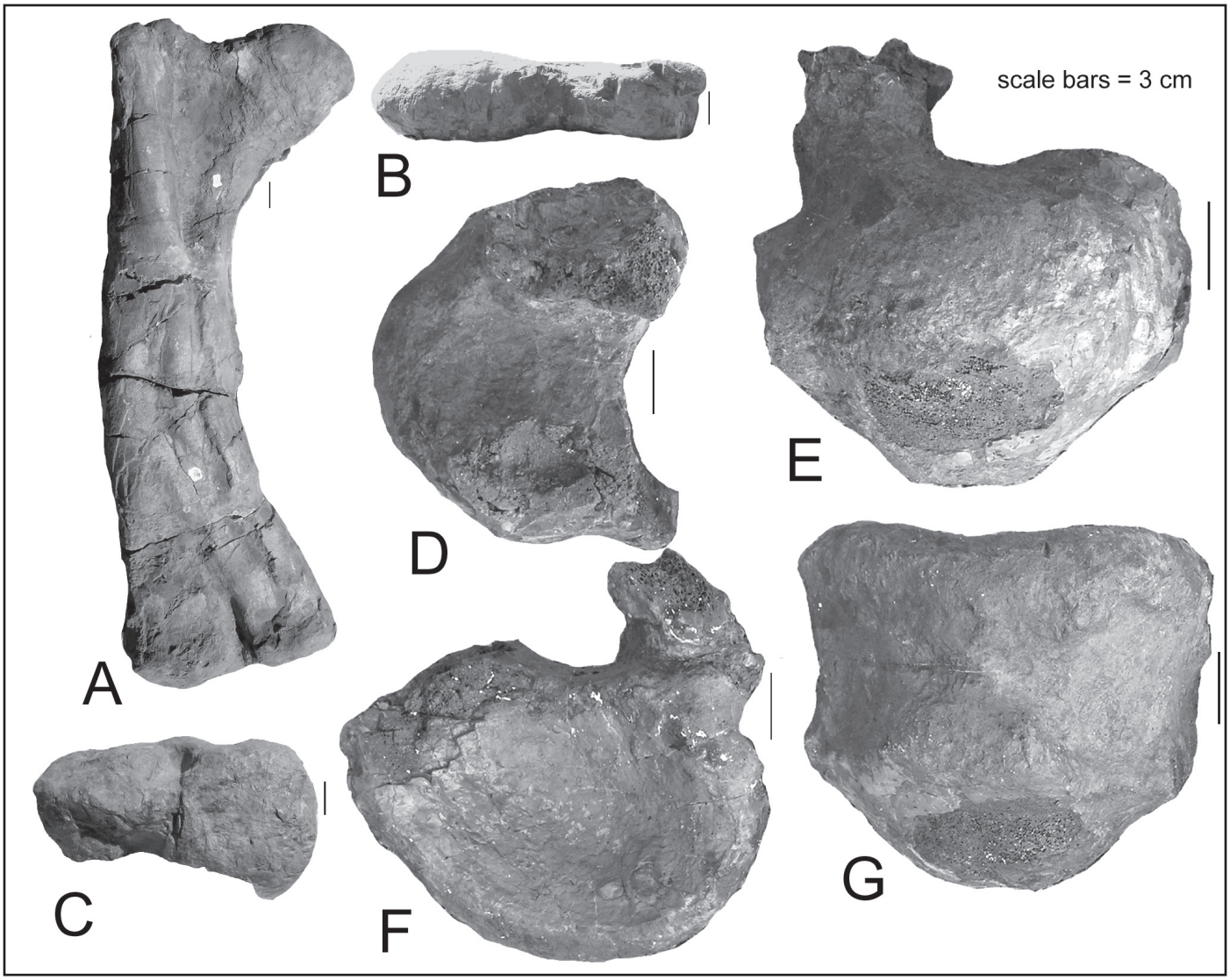

FIGURE 2. Selected dinosaur fossils from the Cretaceous of southeastern Arizona. **A-C**, UALP 4638, left femur of cf. *Tenontosaurus* (Shellenberger Canyon Formation, Empire Mountains) in **A**, posterior, **B**, proximal, and **C**, distal views. **D-G**, UALP 4005, caudal centurm of a titanosaurid sauropod (Fort Crittenden Formation, Santa Rita Mountains) in **D**, dorsal, **E**, anterior, **F**, posterior and **G**, ventral views. Scale bars = 3 cm.

Albian-Cenomanian Cintura and Mojado formations to the east (Archibald, 1987). In the Whetstone Mountains, the marine interval of the formation yields late Aptian invertebrate fossils, as well as pycnodontid fish (Archibald, 1987). The cf. *Tenontosaurus* femur is from stratigraphically above this level, and *Tenontosaurus* is a Cashenranchian (Albian) index fossil in Wyoming, Montana and Texas (Lucas, 1993). Therefore, an Albian age for the ornithopod femur from the Empire Mountains seems likely (Fig. 3).

Whetstone Mountains

In the Whetstone Mountains, the Shellenberger Canyon Formation also yielded an "iguanodontid" femur (Miller, 1964) subsequently identified as *Tenontosaurus* (Galton and Jensen, 1979). Like the similar record in the Empire Mountains, this one is of Albian age. Note that Archibald (1987, p. 276) reported identifications by R. W. Scott of bivalves from the marine interval of the Shellenberger Canyon Formation, which is stratigraphically below the dinosaur record. Recent fieldwork by us, in collaboration with W. R. Dickinson, has confirmed that this interval is of late Aptian age (Fig. 3).

The brachiosaurid sauropod *Sonorasaurus thompsoni* is from the upper part of the Turney Ranch Formation, as are indeterminate turtle fragments and a theropod tooth (Thayer, 1995; Ratkevich, 1997, 1998; Curtice, 2000; Scarborough, 2000) and other, indeterminate dinosaurs. Turney Ranch strata are fluvial siliciclastics homotaxial to upper Albian-Cenomanian? strata of the middle-upper parts of the Cintura and Mojado formations to the east (Archibald, 1982, 1987; Klute, 1991; Soreghan, 1999; Dickinson and Lawton, 2001). K/Ar ages on authigenic illite that stratigraphically bracket the *Sonorasaurus* locality are 96.7±2.4 Ma and 97.7±2.2 Ma (Klute, 1991; Damon et al., 1996), which is very close to the Albian-Cenomanian boundary on the Gradstein et al. (2004) Cretaceous numerical timescale (Fig. 3). Curtice (2000) also noted that *Sonorasaurus* is strikingly similar to sauropod specimens described by Ostrom (1970) from the Albian (Cashenranchian) Cloverly Formation of Wyoming-Montana. These lines of evidence thus support a late Albian age for the *Sonorasaurus* occurrence in the Turney Ranch Formation, though an early Cenomanian age is remotely possible. We also note here that, although Curtice (2000) states that *Sonorasaurus* is strikingly similar to *Brachiosaurus*, he now believes the two taxa are distinct (B. Curtice, pers. comm., 2000).

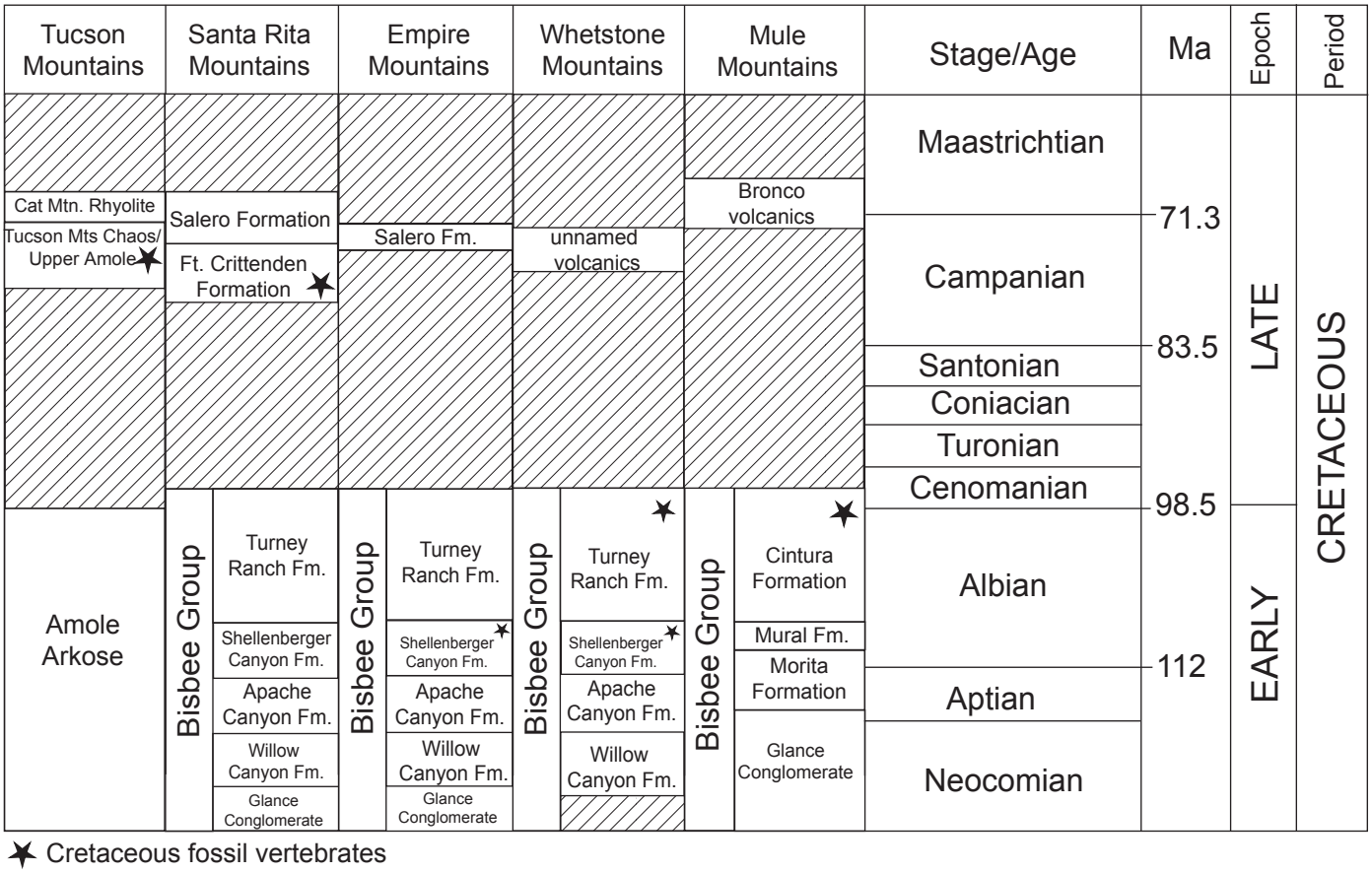

FIGURE 3. Correlation chart of Cretaceous vertebrate localities in southeastern Arizona.

Mule Mountains

Hayes (1970a) reported a small dinosaur? bone from the upper part of the Cintura Formation in the Mule Mountains, strata of late Albian age (Fig. 3). However, nothing more is known about the identity of the dinosaur bone.

Tucson Mountains

The Tucson Mountains have yielded a single ornithopod dinosaur fossil, the "Tucson Mountains dinosaur." This specimen has been referred to as an Early Cretaceous iguanodontid (McCord and Tegowski, 1996; Ratkevich, 1997; Weishampel et al., 2004). The specimen is assigned to a hadrosaur by Lucas et al. (2005), which indicates a Late Cretaceous (probably Campanian) age. Rocks of both Early and Late Cretaceous ages are known from the Tucson Mountains caldera (Lipman, 1993), and it is apparent that the megabreccia block that yielded the Tucson Mountains dinosaur likely represents a portion of the Amole Arkose that is of Campanian age (Lucas et al., 2005) (Fig. 3).

Adobe Canyon

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 in Adobe Canyon in the Santa Rita Mountains (Fig. 1). 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*, lepisosteid gars, pycnodontid fish, the bowfin *Melvius* sp., cf. *Pachyrizodus* sp., *Palaeolabrus montanensis*, the turtles *Adocus*, *Plastomenus*, *Helopanoplia distincta* and indeterminate trionychids, a polyglyphanodontid lizard, alligatoroid and other crocodilians 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, 1997; McCord et al., 2001; Heckert et al., 2003). 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 taxa 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, 1992; 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. *Richardestesia* as indeterminate Dromaeosauridae. Note also that McCord et al. (2001) question whether or not some of the fossils Ratkevich and Duffek (1996) based their identifications on are actually from the Fort Crittenden Formation. Ratkevich (1997) also listed "cf. *Edmontosaurus*" from the Fort Crittenden Formation, but this identification, based on thoracic vertebrae (Ratkevich, 1997, fig. 6), is not justified, as hadrosaur postcrania seldom permit iden-

tification below the subfamilial level (e.g., Lull and Wright, 1942; Brett-Surman, 1972).

Most recently, Heckert et al. (2003) documented some Fort Crittenden Formation vertebrates. They are lepisosteid, pycnodontid and amiid fishes, turtles (*Adocus*, trionychids), alligatoroid and other crocodilians, hadrosaurs and ceratopsians.

McCord (1997) documented UALP 4005, a titanosaurid caudal vertebral centrum (Fig. 2D-G) from the Adobe Canyon area in the Santa Rita Mountains. This centrum was collected at Miller's (1964) El Pilar Tank locality, which was described as "the east end of El Pilar tank in a side branch of Adobe Canyon " (Miller, 1964, p. 381). This site thus was in the shale member of the Fort Crittenden Formation and also produced some of the fossils reported by Heckert et al. (2003).

Nevertheless, both Inman (1982, 1987) and McCord (1997) erroneously attributed the site to the "upper transitional unit" of Inman, strata of the upper part of the Turney Ranch Formation. These strata crop out at El Pilar Tank but yield no dinosaur bones. Indeed, all the Upper Cretaceous vertebrate fossils known from Adobe Canyon come from the shale member of the Fort Crittenden Formation, including the sauropod centrum UALP 4005 (Heckert et al., 2003).

The Fort Crittenden Formation vertebrates do not provide a sufficient basis for a precise age assignment. The fauna is consistent with either a Campanian or Maastrichtian (Judithian-Lancian) age, but lacks index taxa that would provide a more precise age within that interval. Indeed, it could have been argued that the titanosaurid fossil from the Fort Crittenden Formation indicated a Maastrichtian age, but titanosaurs are now known to have a Campanian-Maastrichtian range in the Rocky Mountain region (Lucas and Sullivan, 2000; Sullivan and Lucas, 2000).

Nevertheless, the Fort Crittenden Formation vertebrates can be assigned a late Campanian (Judithian or Kirtlandian) age (Fig. 3) for two reasons:

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 late Campanian age for the Fort Crittenden Formation using the Gradstein et al. (2004) timescale (Fig. 3).

2. The Fort Crittenden Formation is an obvious correlative of the Ringbone Formation of southwestern New Mexico (Hayes, 1970b; Lawton et al., 1993; Lucas et al., 1995, 2000; Basabilvazo, 2000). Both units are remarkably similar lithologically, occupy the same stratigraphic position and have similar vertebrate fossil assemblages (Lucas et al., 1990, 1995; Hunt and Lucas, 1993; 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 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 (Fig. 3).

Other possible records

Two other, undocumented records of vertebrate fossils from the Cretaceous of southern Arizona are: (1) a dromaeosaurid and cf. *Tenontosaurus* from Lower Cretaceous strata in the Huachuca Mountains (Ratkevich, 1997); and (2) a stegosaur from the Lower Cretaceous San Wells Formation near Sells southwest of Tucson (Miller, 1964; Heindl, 1965; Ratkevich, 1997). To our knowledge, these specimens are either lost or not reposited in any museum, so we cannot comment further on them.

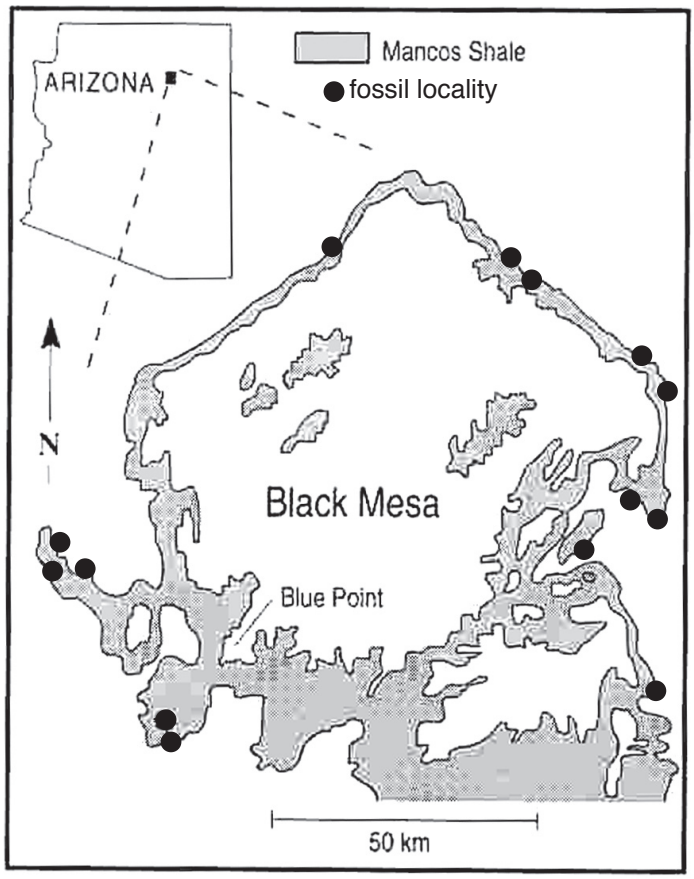

FIGURE 4. Simplified geologic map of Cretaceous outcrop belt of the Black Mesa basin showing principal vertebrate localities (after Williamson et al., 1993 and Elliott et al., 1997).

NORTHEASTERN ARIZONA

Stratigraphic Setting

Near Kayenta in northeastern Arizona, the Black Mesa basin (Fig. 4) exposes an Upper Cretaceous section of the Dakota, Mancos and Toreva formations approximately 250 m thick (Kirkland, 1991, 1996). These are marine and marginal marine deposits of the Greenhorn cyclothem and are of late Cenomanian to middle Turonian age.

Marine Vertebrates

Most of the documented vertebrate fossils from the Black Mesa basin are teeth of chondrichthyans from the Dakota, Mancos and Toreva formations (Williamson et al., 1993). An exception is ornithopod dinosaur tracks and tail drags from the Toreva Formation recently documented by Irby and Albright (2002).

The selachian fauna from the Black Mesa basin consists of 21 taxa: *Hybodus* sp., *Ptychodus whipplei*, *P. decurrens*, *P.* cf. *P. mammillaris*, *Chiloscyllium greeni*, *Chiloscyllium* sp., *Scapanorhynchus raphiodon*, *Cretodus semiplicatus*, *Cretolamna appendiculata*, *C. woodwardi*, *Cretoxyrhina mantelli*, cf. *Leptostyrax* sp., *Squalicorax falcatus*, *Rhinobatis* sp., *Pseudohypolophus mcnultyi*, *Protoplatyrhina hopii*, *Ischyrhiza schneideri*, *I. avonicola*, *Onchopristis dunklei*, *Ptychotrygon triangularis*, *P. rubyae* and five types of dermal denticles. Both nearshore and deeper water selachian assemblages can be recognized.

Many of the selachian taxa from the Cenomanian-Turonian strata of the Black Mesa basin are also known from correlative sites in other parts of North America as well as in Europe and North Africa. They well represent a cosmopolitan selachian fauna of the Cenonanian-Turonian seaways (Williamson et al., 1993).

The other Cretaceous vertebrate body fossils from the Black Mesa Basin are a sparse record of marine reptiles (Gregory, 1917; Lucas, 1994; Irby, 1995; Elliott et al., 1997). These are a turtle (*Desmatochelys*), and crocodilian, plesiosaur (*Trinacromerum*) and mosasaur records.

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Stan Krzyzanowski and Rich Thompson assisted in the field and shared valuable knowledge about numerous localities. Fieldwork with W. R. Dickinson also improved our understanding of the stratigraphic distribution of Cretaceous vertebrates in southern Arizona. E. H. Lindsay and W. R. Dickinson made access to the UALP collection possible. Reviews of this manuscript by B. Albright, W. R. Dickinson, A. Hunt, R. McCord and J. Spielmann are acknowledged.

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