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NO DEFINITIVE EVIDENCE OF PALEOCENE DINOSAURS IN THE SAN JUAN BASIN

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ABSTRACT

In a recent article in this journal, Fassett (2009) concludes that dinosaur fossils of Paleocene age are present in the San Juan Basin of New Mexico-Colorado. However, we argue that, based on existing data, Fassett has failed to produce compelling evidence to support this conclusion. In the San Juan Basin, only one arguably reworked dinosaur bone (an isolated hadrosaur femur) is stratigraphically above undisputed Paleocene pollen, so palynology does not demonstrate Paleocene dinosaurs in the San Juan Basin. Nor does magnetostratigraphy, because Fassett's disregard of a major unconformity above the dinosaur-bearing Naashoibito Member renders questionable his use of an uninterrupted magnetostratigraphy to assign a Paleocene age to dinosaur fossils in that unit. Moreover, Fassett's article failed to adequately dismiss the broadly held conclusions that: (1) the Cretaceous-Tertiary boundary is within the Ojo Alamo Sandstone; (2) the dinosaur-dominated vertebrate fossil assemblage of the lower Ojo Alamo Sandstone (Alamo Wash local fauna of the Naashoibito Member) is of Maastrichtian age; and (3) the isolated, water-worn and/or fragmentary dinosaur bones from the overlying Kimbeto Member are reworked from underlying Cretaceous strata.

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INTRODUCTION

Fassett (2009) claimed that dinosaur fossils are present in strata of Paleocene age in the San Juan Basin of New Mexico-Colorado. As the late astronomer Carl Sagan frequently said, "extraordinary claims require extraordinary evidence," and we believe that Fassett has failed to provide the extraordinary evidence needed to conclude that dinosaurs lived during the Paleocene. Fassett (2009) based his claim primarily on palynologic and magnetostratigraphic data, but also used geochemical analyses to support his conclusions. Here, we address these arguments to demonstrate that based on the data analyzed by Fassett there is no robust scientific basis for assigning a Paleocene age to any dinosaur fossil in the San Juan Basin. Place names referred to here are located in Fassett (2009, figure 1).

LITHOSTRATIGRAPHY

In the San Juan Basin, the Ojo Alamo Sandstone (=Formation of Lucas and Sullivan 2000) yields the supposed Paleocene dinosaur fossils and, according to all workers except Fassett, includes strata of both Cretaceous and Paleocene age. The Ojo Alamo Sandstone as used by Fassett (2009) and by us is the same unit originally defined by Bauer (1916); we do not use the term Ojo Alamo Sandstone as did Baltz et al. (1966), who restricted the term to the upper part of the original rock formation (Kimbeto Member of Figure 1).

In the southwestern San Juan Basin (between Hunter and Betonnie Tsosie washes/arroyos), where most of the dinosaur-bearing localities of the Ojo Alamo Sandstone are located, the lower part of the Ojo Alamo is a basal conglomerate overlain by a finer-grained, poorly consolidated sandstone-to-shale interval ("shale" to many workers), which is the Naashoibito Member (Figure 1). The Naashoibito Member contains the only known articulated dinosaur bones in the Ojo Alamo Sandstone (e.g., Hunt and Lucas 1991; Sullivan pers obser.). The overlying conglomeratic sandstone interval is the Kimbeto Member, which contains only isolated dinosaur bones and bone fragments – these are the stratigraphically highest dinosaur fossils in the New Mexico portion of the San Juan Basin (Fassett et al. 1987; Powell 1973). The Naashoibito Member is only recognized in the southwestern part of the San Juan Basin (e.g., Baltz et al. 1966; Lucas and Sullivan 2000). Elsewhere, to the northwest, the Ojo Alamo Sandstone is mostly a complex, multistoried stack of conglomeratic sandstone sheets that we refer to as the Kimbeto Member.

Fassett (2009) did not recognize distinct Naashoibito and Kimbeto members of the Ojo Alamo Sandstone in the southwestern San Juan Basin and thus referred to the unit basinwide as the Ojo Alamo Sandstone. However, the distinction between lower and upper intervals of the Ojo Alamo Sandstone is an important one, whether or not formal lithostratigraphic nomenclature is applied to it. This is because, other than Fassett, there has been long and broad agreement among geologists/paleontologists (e.g., Baltz et al. 1966; Lehman 1981, 1985; Lucas 1981; Lucas et al. 1987; Newman 1987; Hunt and Lucas 1992; Sullivan and Lucas 2003, 2006; Sullivan et al. 2005b; Williamson and Weil 2008) that in the southwestern San Juan Basin, the base of the Paleocene is within the Ojo Alamo Sandstone, at the base of its upper (Kimbeto) member (Figure 1). However, elsewhere in the San Juan Basin, it is possible that the lower part of the Kimbeto Member is Cretaceous. Fassett (2009), however, did not distinguish lower and upper parts of the Ojo Alamo Sandstone, so he combined all fossils from the Ojo Alamo into one fossil assemblage, which he assigned a Paleocene age. Fassett (2009) thus created the impression that the Ojo Alamo Sandstone is a single unit yielding palynomorphs and dinosaur fossils that can be assigned a single age. It has long been recognized, however, that the Ojo Alamo in the southwestern San Juan Basin encompasses two distinct lithosomes that yield fossil assemblages of different ages (Figure 1).

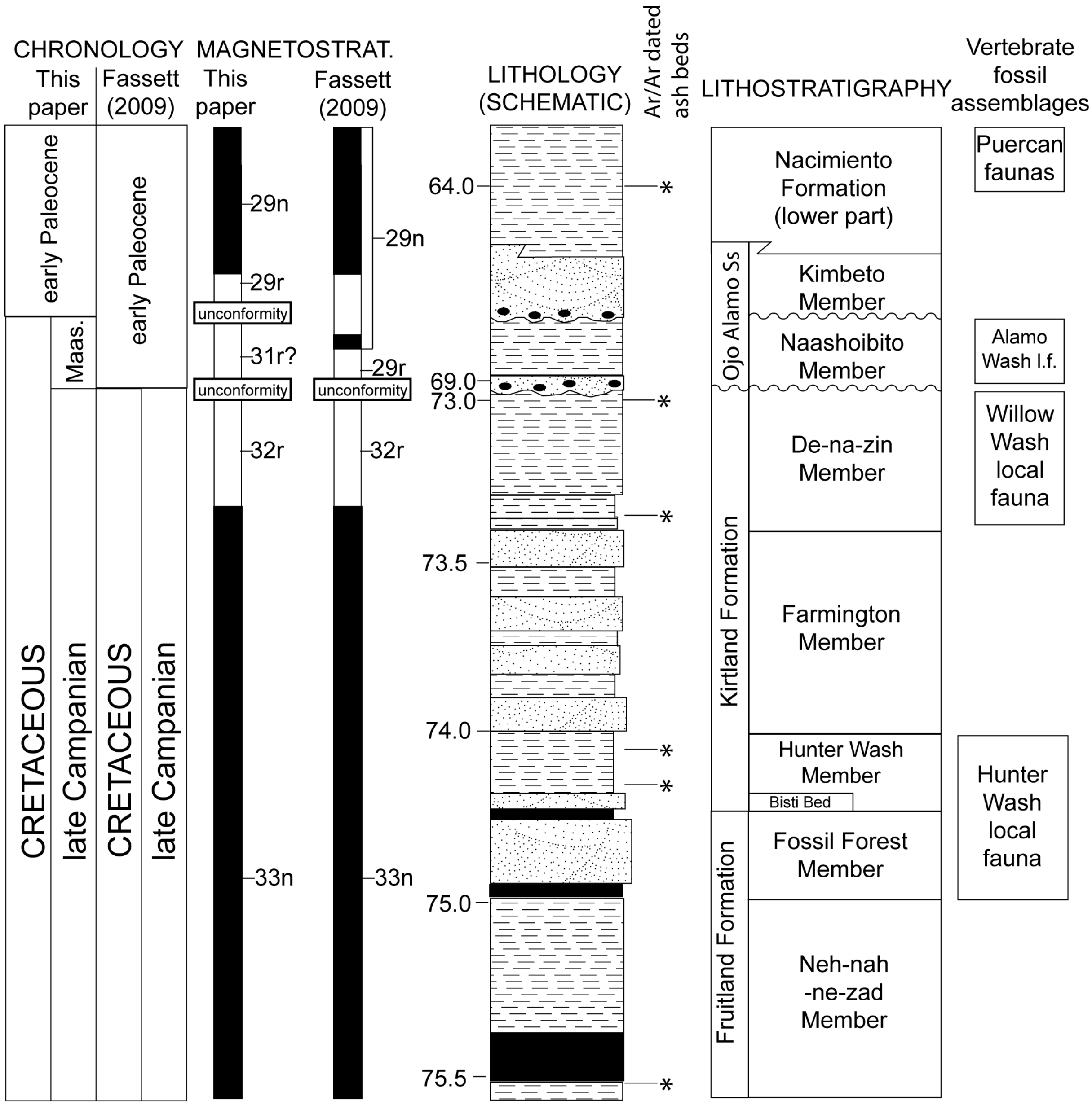

FIGURE 1. Comparison of age determination and magnetostratigraphic correlations advocated in this paper and those of Fassett (2009). The lithostratigraphy and vertebrate fossil assemblages in the southwestern San Juan Basin (right half of diagram) are after Sullivan and Lucas (2006). The magnetostratigraphic columns are those of the Hunter Wash-Barrel Spring Arroyo area, the one area in the San Juan Basin where extensive biostratigraphic and radioisotopic data exist with which to constrain the magnetostratigraphic correlations.

PALYNOLOGY

Fassett (2009) claimed that Paleocene palynomorphs from the Ojo Alamo Sandstone demonstrate its dinosaur fossils are Paleocene in age. Indeed, palynology is the principal database used to support his claim. Yet, despite Fassett's recitation of (mostly) previously published palynostratigraphy, only two localities of Paleocene palynomorphs are claimed by him to be stratigraphically below dinosaur fossils. This is an important point, because as Anderson (1960), Baltz et al. (1966) and others have demonstrated, there are undisputed Paleocene palynomorphs at various localities in the Kimbeto Member of the Ojo Alamo Sandstone, but the dinosaur fossils in the Kimbeto Member are fragmentary and isolated bones, all of which may have been reworked from underlying Cretaceous strata (see Fassett et al. 1987 for a detailed review of most Kimbeto Member dinosaur fossils). No palynomorphs have been reported from the Naashoibito Member, which has yielded an extensive, dinosaur-dominated vertebrate fossil assemblage (the Alamo Wash local fauna of Lehman 1981; Figure 1).

There are two published records of Paleocene palynomorphs stratigraphically below dinosaur bones in the San Juan Basin. Along the San Juan River near Farmington, an essentially complete, and well-preserved, hadrosaur femur was recovered from the Kimbeto Member of the Ojo Alamo Sandstone (Fassett et al. 1987; Fassett and Lucas 2000; Fassett 2009, figure 37.1). The occurrence of Paleocene palynomorphs stratigraphically below this femur has been used to argue that the femur came from a dinosaur that lived during the Paleocene (Fassett et al. 1987, 2002; Fassett and Lucas 2000; Fassett 2009). However, despite the well-preserved nature of the bone, Sullivan et al. (2005b) concluded that the bone has been reworked but not transported any significant distance, thereby preserving the integrity of the bone's outer surface. Indeed, the isolated occurrence of the femur indicates transportation of the bone must have occurred following decomposition, disarticulation and dismemberment of the hadrosaur. The well-preserved nature of the element does not preclude reworking. There are many examples of reworked fossils, including upper Paleozoic brachiopods found among the pebbles of the Ojo Alamo Sandstone (pers obser.), which preserve shell morphology in great detail, and pristine but reworked dinosaur teeth in Paleocene channel bottoms in Montana (Argast et al. 1987; Lofgren et al. 1990; Lofgren 1995).

The second example of supposed Paleocene palynomorphs below dinosaur fossils in the San Juan Basin is a carbonaceous shale ("lignite") bed in the uppermost De-na-zin Member of the Kirtland Formation at Barrel Springs (De-na-zin Wash) in the southwestern part of the basin that Fassett et al. (2002) claimed contains Paleocene palynomorphs, a claim repeated by Fassett (2009). However, two of us (RMS and SGL) sampled that bed in 2000 and reported palynomorphs that included Maastrichtian species, such as "*Proteacidites*" (=*Tschudypollis*) *retusus* and "*P.*" (=*Tschudypollis*) *thalmanni*, as well as *Pandaniidites typicus* and *Ulmoideipites krempi*; no palynomorphs indicative of a Paleocene age were recovered (Sullivan et al. 2005b). Upon being informed of the results, Fassett (personal commun., 2001) claimed that RMS and SGL had actually not sampled the correct stratigraphic level, which according to him, is about 1 m higher in the same bed (Fassett 2009, figure 63). Accordingly, in 2001, RMS and SGL sampled stratigraphically higher in the carbonaceous shale bed, but processing of several samples yielded no identifiable palynomorphs (Sullivan et al. 2005b). Indeed, Fassett et al. (2002, p. 319) reported a late Campanian to early Maastrichtian assemblage of palynomorphs from the lower part of the carbonaceous shale bed, an assemblage that is essentially identical to that reported by Sullivan et al. (2005b). Thus, because RMS and SGL were unable to replicate the palynological results of Fassett et al. (2002) through repeated sampling, Sullivan et al. (2005b) considered them invalid.

Fassett et al. (2002) and Fassett (2009) attached great significance to a 1985 sample from this carbonaceous shale bed in the uppermost part of the Kirtland Formation, which they concluded indicates a Paleocene age. Based on this age, Fassett et al. (2002) and Fassett (2009, figure 63) inferred that there must be an unconformity within the carbonaceous shale bed in the uppermost Kirtland Formation, representing a hiatus of about eight million years.

However, the age of the De-na-zin Member is late Campanian, about 73 Ma, as is demonstrated by biostratigraphy and by the ash dates documented by Fassett and Steiner (1997) (Sullivan et al. 2005b; Sullivan and Lucas 2006). These dates are consistent with the magnetostratigraphy (Figure 1). There is no physical evidence of an unconformity such as internal scour surfaces or paleosols in the carbonaceous shale bed high in the De-na-zin Member.

MAGNETOSTRATIGRAPHY

Butler et al. (1977) published the first magnetostratigraphy across the K/T boundary in the San Juan Basin and concluded that dinosaur extinction postdated the marine extinction at the end of the Cretaceous. This debate is well summarized by Fassett (2009), and all workers now agree that the interval of long normal polarity that corresponds to the Fruitland Formation and most of the Kirtland Formation is chron 33n (Figure 1). $^{40}Ar/^{39}Ar$ ages of ~75.56-73.04 Ma from this stratigraphic interval (Fassett and Steiner 1997), as well as all biostratigraphy, indicate a late Campanian age, and this constrains the magnetostratigraphic correlation (e.g., Lucas et al. 2006). The overlying reversal, which encompasses the uppermost Kirtland Formation, can be confidently correlated to the oldest part of chron 32r (Figure 1).

At the other end of the stratigraphic section considered here, the earliest Paleocene (Puercan) mammal assemblage from the lower Nacimiento Formation, which gradationally overlies the Kimbeto Member, is from a stratigraphic interval of normal polarity (Figure 1). This has long been correlated to chron 29n, and that correlation (Puercan = chron 29n) is also accepted in Texas, Utah and Montana, where the magnetostratigraphy of Puercan-mammal-bearing strata has also been determined (e.g., Lofgren et al. 2004, figure 3.2). Indeed, Fassett et al. (2007) reported an $^{40}Ar/^{39}Ar$ age of 64.4 ± 0.5 Ma for an ash bed stratigraphically low in the Nacimiento Formation that supports the correlation of the normal polarity interval in the lowest Nacimiento Formation to chron 29n, a correlation also advocated by Fassett (2009).

The problem is how to correlate the magnetic polarity stratigraphy between chron 29n (Puercan) and chron 32r (late Campanian) in the San Juan Basin. This is the stratigraphic interval of the Ojo Alamo Sandstone (Figure 1) and is either totally of reverse polarity (final conclusion of Butler and Lindsay 1985) or is mostly reverse polarity above and below a short normal polarity chron (conclusion of Fassett 2009). These differences result from Fassett's (2009) willingness to resurrect (as valid) a short normal polarity chron that was first recognized by Butler et al. (1977) and later rejected by them as a spurious normal overprint (Butler and Lindsay 1985; Lindsay et al. 1981). We are skeptical that the normal polarity chron in the Naashoibito Member should be recognized again, without any reanalysis of the paleomagnetism of the strata in question, especially because it was rejected by those who did the original analysis. Even if Fassett is correct, inclusion of a short normal chron within the interval of reverse polarity that corresponds to the Ojo Alamo Sandstone does not contradict assigning a Cretaceous age to the Naashoibito Member.

On the global polarity timescale, between chrons 33n and 29n, there are three normal polarity chrons – 32n, 31n and 30n – that should be present, and chron 32 is a composite chron that encompasses three normal chrons (e.g., Ogg et al. 2004). Polarity is mostly negative between the base of 31r (70.45Ma $\pm$ 0.65: Ogg et al. 2004) and the top of chron 31n.1r (~68.5Ma: Lerbekmo 2009; top of chron 31n ~ 67.809 Ma: Ogg et al. 2004). During this ~1.95 m.y. interval there are as many as three short duration normal polarity subchrons (c31r.2n, c31r.1n: Lerbekmo and Braman 2002; c31n.2n: Lerbekmo 2009) that might not typically be detected, but any of which would most parsimoniously explain the normal polarity signal in the Naashoibito Member (Figure 1) if it is in fact genuine (sensu Fassett 2009). This means that between chrons 33n and 29n, there are seven normal polarity chrons (chrons 32n.1, 32n.2, 32n.3, 31r.1n, 31r.2n, 31n.2n and 30n). However, in the San Juan Basin section, there is at most one normal chron between 33n and 29n, so much of the magnetic polarity history must be missing. This is *prima facie* evidence of one or more substantial unconformities in the section. We agree with Fassett (2009) that there is an unconformity at the base of the Ojo Alamo Sandstone (base of the Naashoibito Member), but differ from him on the length of the lacuna represented by the unconformity (Figure 1). Thus, Fassett sees it as an ~8-million-year-long hiatus, an unconformity between late Campanian (~73 Ma) and earliest Paleocene (~65 Ma) rocks. We see it as an unconformity of shorter duration, about 4 million years, between rocks of late Campanian (~73 Ma) and early Maastrichtian (~69 Ma) age. Others, who regard the Alamo Wash local fauna as late Maastrichtian (Lancian) in age, see it as a slightly longer unconformity, ~6 Ma (Williamson and Weil 2008). The important point is that there is broad agreement on a substantial unconformity at the base of the Ojo Alamo Sandstone, so this explains at least some of the missing magnetochrons in the section (Figure 1).

There is also broad agreement that there is a profound unconformity at the base of the Kimbeto Member of the Ojo Alamo Sandstone, at the Cretaceous-Paleocene boundary of most workers (e.g., Baltz et al. 1966; Lehman 1981, 1985; Lucas 1981; Lucas et al. 1987; Newman 1987; Hunt and Lucas 1992; Sullivan and Lucas 2003, 2006; Sullivan et al. 2005b; Williamson and Weil 2008) (Figure 1). Fassett is an exception to this broad agreement; he does not recognize an unconformity within the Ojo Alamo Sandstone, even though the physical stratigraphic evidence of it has been well documented (e.g., Baltz et al. 1966; Powell 1973; Sikkink 1987). This unconformity represents a lacuna of between 2 and 4 million years depending on whether the Alamo Wash local fauna is assigned an early Maastrichtian (Edmontonian) or late Maastrichtian (Lancian) age (compare Sullivan and Lucas 2006 with Williamson and Weil 2008).

Thus, Fassett's (2009) correlation of the magnetostratigraphy recognizes the reversed-normal-reversed interval corresponding to the Ojo Alamo

Sandstone as chrons 29r and 29n (Figure 1). He does so because he believes the fossils in the entire Ojo Alamo Sandstone are Paleocene, based primarily on the disputed palynomorph locality in the uppermost Kirtland Formation just discussed. However, the magnetostratigraphy of the Naashoibito Member alone does not demonstrate it is Paleocene in age. The magnetostratigraphy can only be correlated by reference to a datum – and in this case it has to be a biostratigraphic datum. Cretaceous dinosaurs in the Naashoibito Member would support one magnetostratigraphic correlation, while Paleocene dinosaurs would support another (Figure 1). Based on the vertebrate biostratigraphy, the fossils in the Naashoibito Member have long and widely been regarded as Cretaceous, so the chron(s) here should be older than chron 29. How the chron(s) are precisely correlated depends on whether you regard the unconformity-bounded Naashoibito Member as early Maastrichtian or late Maastrichtian in age.

Significantly, Fassett's (2009) reinstatement of the short normal polarity chron (of Butler et al. 1977) in the Naashoibito Member complicates his case for a Paleocene age for the entire Ojo Alamo Sandstone. Given that he accepted the normal chron in the lower Nacimiento Formation and upper Kimbeto Member of the Ojo Alamo Sandstone as chron 29n (= Puercan), he now is forced to include the reversed interval below it, and the short normal chron in the Naashoibito Member as the older part of chron 29n (Figure 1). This creates a composite chron 29n (normal–reversed–normal) not known in the global polarity time scale (cf. Luterbacher et al. 2004) or in other Paleocene magnetostratigraphic sections in western North America (cf. Lofgren et al. 2004). Like other workers (e.g., Butler and Lindsay 1985; Williamson 1996; Lofgren et al. 2004), we regard the reversed polarity interval below chron 29n in the lower Nacimiento Formation as chron 29r (Figure 1), and this is consistent with evidence that the Kimbeto Member is of Paleocene age. Correlation of the reversed chron (or reversed–normal-reversed chron) that corresponds to the Naashoibito Member remains problematic. This interval correlates to some part of chrons 32, 31 or 30 (our biostratigraphy suggests it is most likely part of chron 31r: Figure 1), but is an obviously incomplete record of that time interval and cannot be unambiguously correlated (Figure 1).

Fassett's assignment of the Naashoibito Member to chron 29n is dependent upon: (1) the disputed pollen locality near the top of the underlying Kirtland Formation, (2) the assumption of an unconformity-free, uninterupted magnetostratigraphic succession that spans the Naashoibito-Nacimiento interval and (3) assignment of a Paleocene age to the Naashoibito dinosaurs, which he then (circularly) uses to correlate the Naashoibito magnetostratigraphy to chron 29n. Fassett's (2009, p. 8) statement that "remnant magnetism of rock strata adjacent to the K-T interface in the San Juan Basin provides an objective geochronological tool for placement of the K-T interface and for estimating a more precise age for the base of the Ojo Alamo Sandstone" is thus questionable. We conclude that magnetostratigraphy does not provide definitive evidence of a Paleocene age for dinosaur fossils in the San Juan Basin.

GEOCHEMISTRY

Fassett et al. (2002) undertook geochemical analyses of dinosaur bones from the Ojo Alamo Sandstone and underlying Kirtland Formation. They concluded that there are distinct differences between Ojo Alamo and Kirtland dinosaur bones in the amounts of uranium (U) and rare-earth elements (REE). Fassett (2009, p. 70) reviewed these results and presented new analyses of additional dinosaur bones to conclude that "the chemically distinct Ojo Alamo Sandstone dinosaur bones were fossilized in place during Ojo Alamo Sandstone (Paleocene) time and cannot be Cretaceous bone reworked from the underlying Kirtland Formation."

We emphasize that the geochemical analyses of Fassett et al. (2002) and Fassett (2009) only demonstrate that the chemistry of fossilization and diagenesis in the Ojo Alamo Sandstone is different from that of the underlying Kirtland Formation, not that the Ojo Alamo Sandstone dinosaur fossils are Paleocene. Differing diagenetic pathways for these units are expectable due to the greater permeability of the coarse-grained Ojo Alamo Sandstone.

The geochemical analyses also provide important data not addressed by Fassett (2009) and evident in his figure 44 – the San Juan River hadrosaur bone has geochemical values that overlap the values of Kirtland Formation bone; indeed, it has virtually identical values to a bone from the Kirtland Formation. By Fassett's assumptions, this provides geochemical evidence that the San Juan River hadrosaur bone was fossilized as part of the Kirtland Formation geochemical system, so its presence in the Ojo Alamo Sandstone could only be due to reworking (see above).

Vertebrate Biochronology

Fassett's (2009, p. 53) claim that "vertebrate paleontology has had limited biochronologic value in determining the age of strata adjacent to the K-T interface in the San Juan Basin" contradicts the long-standing success of vertebrate biochronologic methods. Vertebrate fossils have been the primary means by which the K/T boundary has been located in the San Juan Basin since Brown (1910). Furthermore, the Puercan and Torrejonian land-mammal "ages" were defined in the San Juan Basin, and since the 1940s have provided a standard for biochronological correlation of Paleocene mammal faunas in western North America (e.g., Lofgren et al. 2004). The dinosaur-dominated assemblages of the Fruitland and Kirtland formations provided the basis for the Kirtlandian land-vertebrate age (Sullivan and Lucas 2003, 2006) and are classic and long-studied late Campanian vertebrate fossil assemblages since the pioneering work of Gilmore and Sternberg in the 1920s. Finally, the dinosaur-dominated vertebrate fossil assemblage of the Naashoibito Member (the Alamo Wash local fauna) has long been recognized as the youngest Cretaceous vertebrate fossil assemblage in the San Juan Basin (see reviews by Lucas 1981; Lucas et al. 1987; Hunt and Lucas 1992; Lucas and Sullivan 2000; also see bibliography posted at www.nmfossils.org).

Not only is Fassett (2009) dismissive of vertebrate biochronology, but his identification of Paleocene dinosaurs in the San Juan Basin contradicts published data that run counter to his correlations and assessment of the value of vertebrate biochronology in placement of the K/T boundary in the San Juan Basin and elsewhere. Indeed, across the Western Interior, and in particular in Texas and Utah, there are vertebrate fossil assemblages that contain dinosaurs, mammals, turtles and crocodylians that are similar to (or the same taxa as) those found in the Naashoibito Member of the Ojo Alamo Sandstone, and these have long been correlated to the Alamo Wash local fauna (e.g., Lehman 1981, 1985; Sullivan and Lucas 2006). Particularly similar to the Alamo Wash local fauna are the dinosaur-dominated assemblages of the North Horn Formation in eastern Utah and the Javelina Formation of the Big Bend region in Texas. Various data from these non-New Mexican sections indicate these are Late Cretaceous vertebrate assemblages (e.g., Cifelli et al. 1999; Difley 2007; Difley and Ekdale 1999; Lehman et al. 2006). So, it strikes us as extraordinary that Fassett (2009) claimed that only in the San Juan Basin is such a vertebrate fossil assemblage of Paleocene age. Indeed, if the Alamo Wash local fauna is Paleocene, then do we need to rethink the ages of the vertebrate fossil assemblages of units such as the Javelina Formation in Big Bend or the North Horn Formation in Utah?

We also stress that vertebrate biochronology of the K/T boundary in the Western Interior relies heavily on an extensive and detailed mammalian biostratigraphy. Fassett's (2009) discussion ignored the large body of literature on mammal correlations across the K/T boundary that place the Alamo Wash local fauna in the Cretaceous and the Puercan assemblages, of the overlying Nacimiento Formation, in the early Paleocene. This body of work should have been addressed, because if the Alamo Wash local fauna mammals are Paleocene, then age determinations based on mammals from Alberta to Texas must be revised. We note that the mammal genera of the Alamo Wash local fauna, such as *Alphadon*, *Essonodon* and *Meniscoessus*, are not known elsewhere from Paleocene strata. They are characteristic Late Cretaceous mammals (Cifelli et al. 2004; Lehman 1984; Lofgren et al. 2004; Williamson and Weil 2008).

There is room to argue about the precise age within the Maastrichtian of the Alamo Wash local fauna, and this is a subject of discussion among vertebrate paleontologists (compare Sullivan et al. 2005a to Williamson and Weil 2008). However, this in no way diminishes the value of vertebrate biochronology to indicate that the K/T boundary in the San Juan Basin is between the stratigraphically highest *in situ* dinosaur fossils (in the Naashoibito Member of the Ojo Alamo Sandstone) and the stratigraphically lowest Puercan mammal fossils (in the Nacimiento Formation) (Figure 1).

Finally, there is another questionable issue, discussed by Fassett (2009, p. 58-60)- - his claim of Paleocene dinosaurs in the Animas Formation. Fassett based this claim on an unpublished "*Triceratops*" specimen found 11 m above the base of the Animas Formation and a Paleocene flora, published by Knowlton (1924), found "about 60 m above the base of the Animas to near its top more than 500 m above the base of the formation" (Fassett 2009, p. 58). Clearly, the dinosaur specimen is stratigraphically below the Paleocene plant fossils, so how can the plant fossils indicate a Paleocene age for the dinosaur? Furthermore, the dinosaur fossil is stratigraphically below the lowest Paleocene palynomorphs reported from the Animas Formation, which are about 30 m above its base (Newman 1987, p. 158).

CONCLUSIONS

We conclude that Fassett (2009) has failed to produce the compelling evidence needed to support his extraordinary claim that Paleocene dinosaur fossils are present in the San Juan Basin. Existing data do not uniquely support his claim. Thus, only one arguably reworked hadrosaur femur is stratigraphically above undisputed Paleocene pollen. So, palynology does not demonstrate Paleocene dinosaurs in the San Juan Basin. Nor does magnetostratigraphy, because (among other things) Fassett's disregard of a major unconformity above the dinosaur-bearing Naashoibito Member renders questionable his use of magnetostratigraphic correlation to assign a Paleocene age to dinosaur fossils in that unit. Moreover, Fassett's (2009) article failed to adequately dismiss the broadly held conclusions that: (1) the K/T boundary is within the Ojo Alamo Sandstone; (2) the dinosaur-dominated assemblage of the lower Ojo Alamo Sandstone (Alamo Wash local fauna of the Naashoibito Member) is of Maastrichtian age; and (3) the isolated, water-worn and/or fragmentary dinosaur bones from the overlying Kimbeto Member are reworked from underlying Cretaceous strata.

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Spencer Lucas received a B.A. from the University of New Mexico in 1976, and M. S. (1989) and Ph.D. (1984) degrees from Yale University. His research interests have primarily focused on vertebrate biostratigraphy, particularly of the Mesozoic. Lucas is particularly interested in the application of vertebrate fossils to problems of the geologic timescale. He has conducted field research primarily in the western United States, but also in China, Kazakstan, Georgia, Mexico, Costa Rica and Nicaragua.

Lucas began fieldwork in the San Juan Basin, New Mexico in 1976, studying the Eocene San Jose Formation and its mammal fossils. In 1977, he expanded that work into the Cretaceous and Paleocene strata and fossils. Currently, most of his research in the San Juan Basin is on problems of Upper Cretaceous biostratigraphy in collaboration with Robert Sullivan.

Since 1988, Lucas has been Curator of Geology and Paleontology at the New Mexico Museum of Natural History and Science.

Photo: Spencer Lucas with the cast of tyrannosaur footprint.

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Robert Sullivan received his B.A. in Geology from the University of New Mexico in 1973, followed by a year of post-baccalaureate study at the University of Nebraska-Lincoln in 1974, received a M.S. in Vertebrate Paleontology from San Diego State University in 1978, and a Ph.D. in Geology from Michigan State University in 1980. His research interests are in the broad field of paleoherpetology, focusing on the lower vertebrates (turtles, lizards and crocodylians) and dinosaurs, Late Cretaceous vertebrate biochronology, as well as the controversial topic of dinosaur extinction.

Since 1979 Robert has been actively pursuing fieldwork in San Juan Basin, New Mexico, collecting non-mammalian vertebrates from the Fruitland, Kirtland and Nacimiento formations. He received a NSF grant (BSR-8407342) for his project "Revision of the Puerco Fauna. Part 1: The Lower Vertebrate Microfauna" in August 1984. In 1995, he turned his attention to the Kirtland and Ojo Alamo formations, to actively resample the dinosaurs and other fossil vertebrates of the De-na-zin and Naashoibito members, respectively. Some of his more noteworthy discoveries include a new specimen of the rare lambeosaurine dinosaur *Parasaurolophus tubicen* (the second and most complete specimen known of the genus) and a new ankylosaurid dinosaur *Nodocephalosaurus kirtlandensis,* which he named in 1999. In 2003, he and colleague Spencer G. Lucas, defined the “Kirtlandian” a new land-vertebrate age for the Late Cretaceous of western North America. In recent years he has become the leading authority on pachycephalosaurids dinosaurs and has published a number of papers on these enigmatic ornithischians.

He has taught numerous college level geology and paleontology courses and has extensive museum experience. Presently, he is in his 17th year as Senior Curator of Paleontology and Geology at The State Museum of Pennsylvania, Harrisburg.

Photo: Robert M. Sullivan with a partially exposed femur of the Late Cretaceous sauropod *Alamosaurus sanjuanensis* in the Naashoibito Member (Ojo Alamo Formation) near Barrel Springs, San Juan Basin, New Mexico.

Steven M. Cather

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Steven M. Cather is a native of southern California. He received his Bacheor's degree from New Mexico Tech in 1976. His graduate degrees are from the University of Texas at Austin (M.A., 1980; Ph.D., 1986). Cather's scientific interests are broad and include depositional systems, basin analysis, regional tectonics, structural geology, and paleoclimatology.

Steve Cather is employed as a Senior Field Geologist at the New Mexico Bureau of Geology and Mineral Resources, a division of New Mexico Institute of Mining and Technology. He has conducted diverse, field-oriented geologic research throughout New Mexico and parts of Colorado and Wyoming. His current research topics include the geologic evolution of the San Juan Basin and the slip history of the Picuris-Pecos fault.

Photo: Steven M. Cather in the office.

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Steven Jasinski received a BSc degree in Geobiology from Pennsylvania State University in 2008. He has worked at the State Museum of Pennsylvania from January 2008 – present and is currently taking graduate courses in geology at Pennsylvania State University. His interests are in vertebrate paleontology and stratigraphy, focusing primarily on Late Cretaceous vertebrate faunas and vertebrate biochronology. Steve's interest in dinosaurs centers on the study of oviraptorosaurs, ankylosaurs, and pachycephalosaurs. He also recently studied the skull biomechanics of the Late Triassic theropod *Coelophysis*.

Steve has conducted field work in Pennsylvania, as well as Colorado, Utah, Montana, Wyoming, and other states. More recently, he served as a field paleontologist for the State Museum of Pennsylvania in the San Juan Basin of New Mexico, where he collected fossil vertebrates from the Fruitland, Kirtland, and Ojo Alamo formations. He is currently involved in a study revising the taxonomic composition of the Alamo Wash local fauna (Naashoibito Member, Ojo Alamo Formation), as well as revising the biostratigraphy of the Kirtland and Ojo Alamo formations as part of a group project.

Photo: Steven E. Jasinski with a partially exposed dinosaur ulna from the De-na-zin Member (Kirtland Formation), San Juan Basin, New Mexico.

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A native of the United Kingdom, Denver Fowler received a BSc degree in geology from the University of Durham (UK) in 1998, followed by an MSc in palaeobiology from the University of Bristol (UK) in 2000. He conducted graduate work at the University of Rhode Island (2001-2003) and is currently a Ph.D. candidate at Montana State University. His interests are in vertebrate paleontology and stratigraphy, primarily vertebrate biochronology through the Late Cretaceous of North America, including specifically the biostratigraphy of *Alamosaurus*, and ceratopsid biostratigraphy.

Denver has conducted field work in the UK, USA, China and Mongolia, including extensive stratigraphic work on the K-T boundary in Montana. He worked as a vertebrate paleontology field assistant for the State Museum of Pennsylvania for four field seasons (2002-2004, 2006) where he collected fossil vertebrates from Fruitland, Kirtland and Ojo Alamo Formations. Denver is currently conducting a study of the sequence stratigraphy and biostratigraphy of the latest Maastrichtian Hell Creek and Lance Formations.

Photo: Denver sitting next to a jaw of a large ceratopsid from the Naashoibto Member (Ojo Alamo Formation), San Juan Basin, New Mexico.

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Andrew Heckert earned a B.S. in Geology summa cum laude from Denison University in 1993 before earning an M.S. (1997) and Ph.D. (2001) from the Department of Earth & Planetary Sciences at the University of New Mexico. Subsequent to this he worked as the Geoscience Collections Manager at the New Mexico Museum of Natural History (2002-2005) before taking his current post as Assistant Professor in Geology and Director of the McKinney Geology Teaching Museum at Appalachian State University.

His research interests revolve around Late Triassic stratigraphic, biostratigraphic, and paleontologic issues, focusing primarily on microvertebrates, but he enjoys ranging up and down the section, and has collected vertebrates ranging in age from Devonian to Pleistocene, conducting field work across the American West and now in his new home state of North Carolina. His Cretaceous experience involves collecting microvertebrates and other fossil reptiles from the Upper Cretaceous Menefee, Fruitland, and Kirtland formations in the San Juan Basin in New Mexico.

His teaching responsibilities include various introductory courses, a new course titled “Evolution of the Earth,” an honors course on dinosaurs, and summer field trip classes to the American Southwest.

Photo: Andrew Heckert takes a break from stratigraphic and paleontologic work next to a stump of Arizona’s state fossil, the Triassic tree *Araucarioxylon*.

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Justin Spielmann received a BA degree from Dartmouth College in June 2005, graduating as a senior fellow. He has worked as the Geoscience Collections Manager for the New Mexico Museum of Natural History since September 2005. His research interests include North American Late Triassic tetrapods, vertebrate biostratigraphy and functional morphology.

Photo: Justin Spielmann in the office.

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Adrian Hunt has a B.Sc. in Geology from the University of Manchester, an M.S. in Geology from New Mexico Tech and a Ph.D. in Earth and Planetary Sciences from the University of New Mexico. He has worked for almost 30 years at various institutions of higher education and museums.

Adrian first conducted fieldwork in the Late Cretaceous of the San Juan Basin in 1980. Subsequently, he has published on the stratigraphy, sedimentology, vertebrate paleontology, taphonomy and ichnology of the Fruitland and Kirtland formations. With Spencer Lucas, he has named five of the stratigraphic subdivisions of these units and two of their hadrosaurian dinosaurs (*Anasazisaurus* and *Naashoibitosaurus*). Hunt has also published widely on the vertebrate paleontology, ichnology and stratigraphy of the late Paleozoic through late Mesozoic.

Photo: Adrian in his outdoor office.