A paleontological survey of a part of the Tesuque Formation near Chimaya, New Mexico, and a summary of the biostratigraphy of the Pojoaque Member (Middle Miocene, Late Barstovian)

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A PALEONTOLOGICAL SURVEY OF A PART OF THE TESUQUE FORMATION NEAR CHIMAYÓ, NEW MEXICO, AND A SUMMARY OF THE BIOSTRATIGRAPHY OF THE POJOAQUE MEMBER (MIDDLE MIOCENE, LATE BARSTOVIAN)

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Abstract—A recent paleontological survey north of Chimayó, NM, identified many new localities containing Miocene mammal fossils and one site containing freshwater(?) gastropods. All fossils were found within eight sections (T21N, R9E) at the southwest end of the survey area within the Pojoaque Member of the Tesuque Formation. The majority of the fossils were found within ~120 m stratigraphic interval containing the Pojoaque white ash zone, which to the south contains an ash that is 13.7 ± 0.18 Ma. Correlation of the Pojoaque white ash zone with the magnetic-polarity stratigraphy of Barghoorn, (1981), indicates an age range of 14.0-13.2 Ma for this ash zone. All fossils were found within sediments derived from Proterozoic metamorphic and Paleozoic sedimentary (sandstone, limestone, and shale) terrains to the northeast with minor and variable input of volcaniclastic material from the Latir vocanic field near Taos. Laterally adjacent and overlying sediments derived primarily from Proterozoic granite to the east are barren of fossil material. The fossil-bearing strata have been interpreted to represent a basin-floor environment while the barren, granitic sediments are interpreted as a piedmont environment. Preferential fossilization may reflect either different diagenetic conditions in the lime-bearing sediments relative to the sediments derived primarily from Proterozoic sources or reflect some inherent difference in depositional environment. A compilation of published paleontological data along with our recent findings produces a summary of the known fauna of the Pojoaque Member of the Tesuque Formation. Approximately 65 species of mammals are currently known from the Pojoaque Member, which represents one of the most important samples of early late Barstovian (early middle Miocene) mammals in western North America.

HISTORY OF STUDY AND OUTLINE OF STRATIGRAPHY

The Santa Fe Group (Spiegel and Baldwin, 1963) was extensively sampled for vertebrate remains by the American Museum of Natural History between 1924 and 1960 (Galusha and Blick, 1971). Less-extensive sampling was conducted as early as the 1870's by E.D. Cope and by the New Mexico Museum of Natural History since the 1970s. The American Museum collections include at least 20,000 "major skeletal elements", but only about 30% had been "formally catalogued" into their collection as of 1979 (Kues and Lucas, 1979, p. 238). No comprehensive assessment or description of these specimens has been conducted and little information on the location or stratigraphic context of the specimens is available in published form. What information is available is restricted to monographs or reports on individual taxa (see Kues and Lucas, 1979 and McKinney et al., 2001 for references).

The Santa Fe Group includes Oligocene-Quaternary basin-fill of the Española Basin of the Rio Grande rift (Spiegel and Baldwin, 1963). In the study area these rocks have been subdivided in two different ways. Galusha and Blick, (1971) defined a stratigraphy consisting of the Tesuque Formation with five members (Nambé, Skull Ridge, Pojoaque, Ojo Caliente Sandstone, and Chama-El Rito). These members were defined by stratigraphic markers that were based partially on biostratigraphy. The stratigraphic markers used by Galusha and Blick (1971) to define these members were not consistently found in the study area by Koning (2003) and Koning and Manley (2003) and they instead mapped 24 informal lithologic units. Koning (2003) did, however, map an approximate Pojoaque/Skull Ridge contact in the study area (Fig. 1). The divisions of Koning (2003) and Koning and Manley (2003) were based on the work of Cavazza (1986), who defined two sedimentary provinces (A and B) with further subdivisions based on textural and bedding characteristics. Cavazza's provinces were defined by "sandstone and conglomerate petrology" (grain and clast type), paleocurrent data, and "sedimentary facies analysis". The sedimentary provinces of Cavazza (1986) are represented as two "lithosomes" (A and B) by Koning (2003) and Koning and Manley (2003).

In outcrop, these two lithosomes are most easily distinguished by grain and clast type. Gravels of lithosome A are dominated by granite, with lesser quartzite, and the sand fraction is arkosic (Cavazza, 1986; Koning, 2003; Koning and Manley, 2003). In the study area, gravels of lithosome B are mainly Paleozoic sandstone, siltstone, and limestone, with 5-20% Proterozoic quartzite, 0-20% felsic-intermediate volcanic rocks, and 1-5% granite (Koning et al., 2005). The sand of lithosome B is a litharenite to lithic arkose (Koning et al., 2005). Lithosome A has been interpreted as an alluvial slope or piedmont deposit laid down by west-flowing, intermittent streams (Smith, 2004; Kuhle and Smith, 2001), and lithosome B as basin-floor deposits laid down by a south-southwest-flowing river (Koning, et al., 2005).

PURPOSE AND METHODS OF THIS STUDY

In 2009-11 a paleontological survey was conducted on parts of the El Palacio/Fun Valley BLM off-road vehicle area located north of Chimayó and east of Ohkay Owingeh (formerly San Juan Pueblo), New Mexico. The objective of this study was to assess past impacts to fossil resources and limit any future impacts by identifying fossil-rich areas. While Gary Morgan and crews from

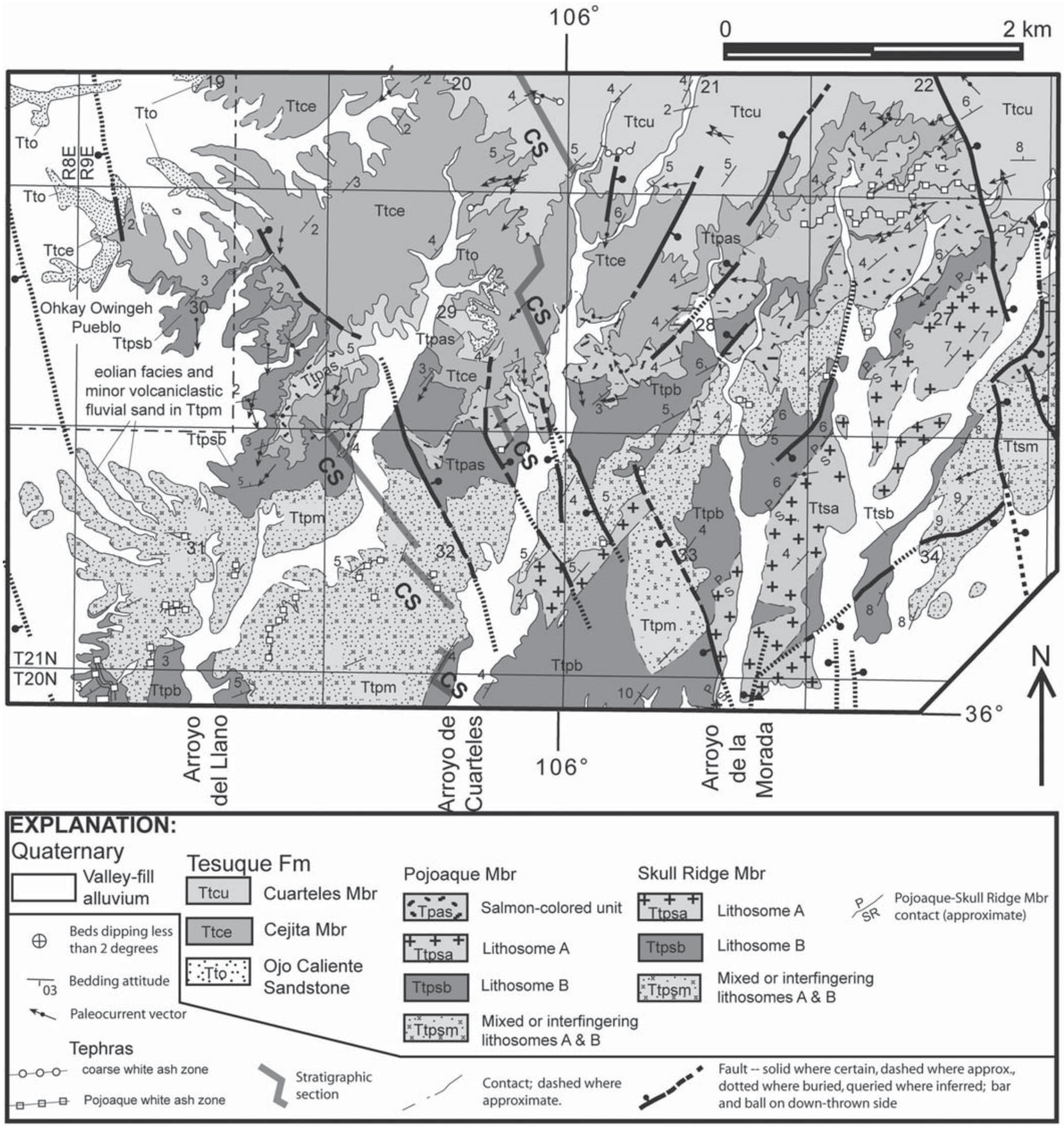

FIGURE 1. Geologic map of the fossil-rich part of the study area. Additional areas to the north and east of figure were surveyed but barren of fossil material. For additional information see Koning (2003) and Koning and Manley (2003). CS=Cuarteles stratigraphic section.

the NMMNH focused on collecting in known fossil-rich areas (Galusha and Blick, 1971; Kues and Lucas, 1979), Scott Aby surveyed all of BLM-managed parts of sections 5, 6, 7, 8, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 30, 31, 32, 33 and 34 and parts of sections 27 and 29, T21N, R9E (Fig. 1). The latter survey was conducted by 'prospecting' major and tributary drainages for fossil material, making transects perpendicular to strike of beds (usually along ridges or in drainages), and then thoroughly searching any fossil-bearing horizons found in these transects. The location of all fossil sites was recorded using a GPS unit and their stratigraphic context was confirmed by field observations and comparison to geologic maps of the area (Koning, 2003; Koning and Manley, 2003). Fossils and fossil data are archived at the New Mexico Museum of Natural History in Albuquerque, NM.

FOSSIL DATA

Sedimentology

Fifty-six individual fossil localities were identified within the twenty-two sections (or parts of sections) surveyed by Aby. Some of these sites consist of multiple, closely spaced fossils. All of these sites were within the eight sections in the southwest part of the study area (within sections 27, 28, 29, 30, 31, 32, 33 and 34 of T21N, R9E; Fig. 1), an area already known to be fossil rich based on the work of the American Museum of Natural History (Appendix 1). Unidentifiable bone 'shards' or 'chips' were also found in section 20 of T21N, R9E.

Fifty-three of the fossil sites are in the Pojoaque Member of the Tesuque Formation and three are in the Cejita Member, but all are from 'lithosome B' sediments (e.g. sediments containing a mixture of Paleozoic sedimentary clasts and Proterozoic (plutonic and metamorphic) clasts ± Cenozoic volcanic clasts). Only five fossil sites are from areas that contained Cenozoic volcanic clasts as part of their pebble-sized component, and such beds are proportionately rare in the study area. It should be noted that the lithosome A or B designation was often made based on the nearest coarse-grained beds in the section, as fossils are commonly found in fine-grained beds. Spot checking confirmed that the pebble-sized fraction matched the general composition of the sand-sized fraction. Thirteen (~23%) of these sites contained material that was unambiguously "in place" (in their original location within the strata) and four more were probably in place. The remainder of the fossil material was found on the surface and may have been transported downslope, although in almost all cases this transport was probably limited to less than 100 m. Fourteen sites were located in or on green or greenish beds that we interpret as indicating reducing conditions and twenty-one sites were on or in red or reddish beds interpreted as indicating strongly oxidizing conditions. The remainder of sites were found in or on tan or brownish sediments interpreted as moderately-to-weakly oxidizing. Thirty-three out of fifty-six (59%) fossil sites were found in units interpreted by Koning (2003) as of 'mixed' provenance (i.e. interbedded lithosome A and B; Figs. 1, 2, Table 1). These sites were found in or on individual beds containing Paleozoic +/- volcanic clasts.

Age

All but one of Aby's fossil sites are above Koning's (2003) projected Pojoaque/Skull Ridge contact (Fig. 1) and are therefore from the Pojoaque Member of Galusha and Blick (1971), which contains fossils from the late Barstovian North American land mammal "age" (NALMA; ~14.5-12 Ma; Tedford and Barghoorn. 1993; Tedford et al., 2004), consistent with the fossils found during our study (Appendix 1). Approximately eighty percent of the fossils we found are within ~1 km of the Pojoaque white ash zone (PWAZ), as mapped by Koning (2003) and Koning and Manley (2003; Fig. 2). The PWAZ is well-exposed 11 km south of here, in the Pojoaque Member type section of Galusha and Blick (1971). Here, one of the lower ashes of the PWAZ has been dated at 13.7 ± 0.18 Ma by the $^{40}Ar/^{39}Ar$ technique (Izett and Obradovich, 2001). Projection of the dated ash to the paleomagnetic section of Barghoorn (1981) (which was measured along the Pojoaque Member type section) allows us to constrain the age range of the Pojoaque white ash zone to 14.0-13.2 Ma. Chemical analyses of ashes in the study area indicates a match for two of these ashes with those in the Pojoaque Member type section (Slate et al., in review). The PWAZ in the Cuarteles measured section is approximately 120 m thick (Fig. 2). Using an average stratal accumulation rate of 0.15 mm/yr for the PWAZ in the study area (Koning et al, 2005), it would take approximately 0.8 Ma to deposit this much sediment.

Environmental Interpretation

At the time the fossils in the study area were deposited, the area was situated near the confluence of a broad, undissected alluvial-slope (lithosome A) and a fluvial basin floor (lithosome B) with highlands to the east and northeast and the Jemez Mountains volcanic field beginning to develop to the west (Kuhle and Smith, 2001, Smith, 2004). With time, the border between the basin floor and alluvial slope environments migrated back and forth across the study area.

Fossil flora that could be used to make local climate inferences for the Miocene in this area were long limited to a palm stump found in the Skull Ridge Member "...a few miles northwest of Santa Fe." (Axelrod and Bailey, 1976). This palm fossil was used

TABLE 1. Representative fossils shown on Cuarteles Strat Section (Figure 2)

NMMNH number	Species	Description
28972	*Gomphotherium productum*	Mastodon
57608	*Meryceros crucensis*	Pronghorn
57620	*Aelurodon ferox*	Borophagine dog
63412	*Aelurodon ferox*	Borophagine dog
63413	*Pseudaelurus stouti*	Small cat
63415	*Pliogale nambiana*	Skunk
63416	*Copemys loxodon*	Rodent
63417	*Neohipparion coloradense*	Horse
63418	*Merychyus medius*	Oreodont
63419	*Merychyus medius*	Oreodont
63420	*Hesperotestudo*	Giant land tortoise
L-7782	Various small vertebrates	Microfauna Quarry

Notes:Number preceded by an "L" is a locality number, all others are catalog numbers.

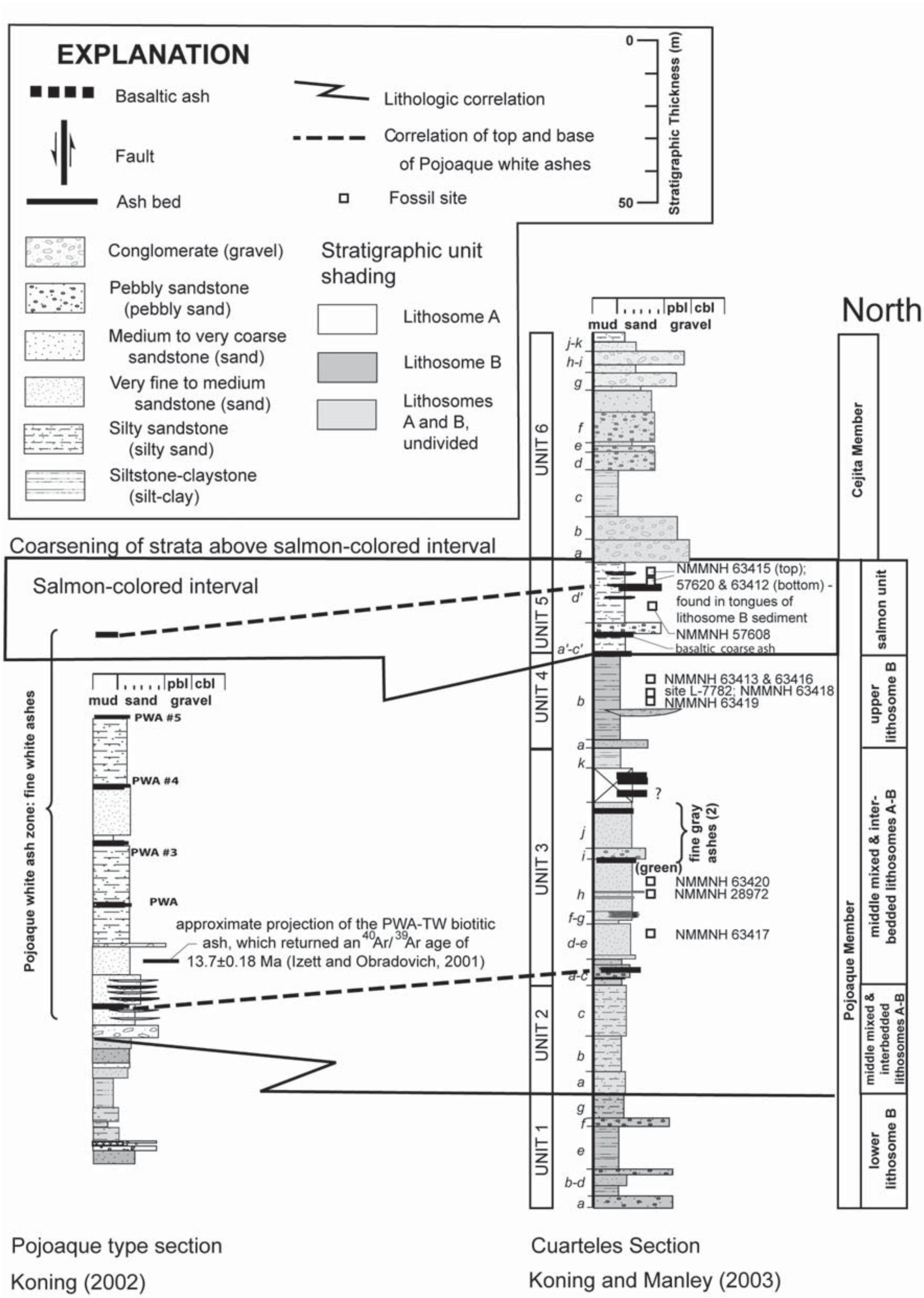

FIGURE 2. Cuarteles stratigraphic section with representative fossil sites projected onto it. Figure also shows correlation with Pojoaque Member type section and its dated ash. Age diagnostic fossils from these sites are listed in Table 1. Note that sites 63415 and 63412, although projecting into the lithosome A "Salmon Interval" of Galusha and Blick (1971,) were found in laterally adjacent lithosome B sediments.

to infer frost-free conditions. Recently, plant-fossil rich horizons have been found in the Pojaoque Member (McKinney, et al., 2006) that contain bristlecone pine and willow fossils among others (McKinney, personal comm., 2011). These new discoveries indicate that the climate varied from frost-free (Palm) to possibly "subalpine" (bristlecone pine) during deposition of the Tesuque Formation as a whole, or possibly that the drainage basin(s) contained this range of environments.

FOSSILIZATION

Clearly, bone was preferentially fossilized within sediments containing a mixture of Paleozoic and Proterozoic clasts (lithosome or province B) as opposed to those derived only from Proterozoic sources (lithosome or province A). The purpose of this study was simply to delineate areas that contain fossils, but we can offer some speculation on why bones were preferentially preserved in one type of sediment. Paleozoic clasts in the study area are dominated by sandstone with subordinate limestone, siltstone and mudstone clasts. Siltstone and mudstone are commonly 'limey' and sandstone commonly has some carbonate cement. We assume, therefore, that the groundwater moving through these sediments immediately after deposition had a higher pH than groundwater moving through the sediments of 'lithosome A'. Lyman (1994) states that preservation of bone is better in high pH (alkaline) environments due, at least in part, to the inhibition of bacterial activity. Many fossils were found in sediments we interpret to represent oxidizing conditions (red, tan, and brownish sediments), so oxidizing conditions did not preclude preservation of bone in the study area. However, as green or greenish beds make up < 5% of the section, but accounted for ~25% of fossil sites, reducing conditions probably did favor bone preservation even within the context of overall good preservation potential.

The two types of sediment (A and B) have been interpreted as representing different depositional environments. Cavazza (1986) interpreted province A as an "...ephemeral environmental regime..." and province B as "...a more perennial regime." (Cavazza, 1986, p. 287). This may have led to quicker burial of bone in lithosome B environments and therefore enhanced preservation potential. The abundance of fossils in sediments interpreted to represent interbedding of the two sediment types (Koning, 2003; Koning and Manley, 2003) may also reflect faster burial in these environments or some other factor unique to this depositional environment.

Many parts of the Tesuque Formation that contain abundant Paleozoic clasts do not contain fossils or are very sparsely fossiliferous; for example the Dixon and Cejita members to the north of the study area are barren (Koning and Aby, 2003; Manley, 1977, Morgan et al., this volume). By the same token, some highly fossiliferous parts of the Tesuque Formation contain no Paleozoic clasts (e.g., the Chama-El Rito Member near Medanales, NM; Koning et al., 2004). Factors unique to each fossiliferous part of the Santa Fe Group must therefore account for preservation in each area.

BIOSTRATIGRAPHY OF THE POJOAQUE MEMBER

The area surveyed during this study encompasses much of the Frick Laboratory "Santa Cruz fossil-collecting locality" (Galusha and Blick 1971, fig. 2; Fig. 1). Historically, this has been one of the richest areas for Miocene vertebrate fossils in the entire Española basin (e.g., Galusha and Blick, 1971; Tedford, 1981). The most productive of the Santa Cruz fossil sites are in the Pojoaque Member of the Tesuque Formation in Arroyo del Llano (First Wash of the Frick Laboratory) and Arroyo de Quarteles (Second Wash of the Frick Laboratory). East of Arroyo de la Morada (Third Wash of the Frick Laboratory), exposures are in either the Skull Ridge or Nambé Members of the Tesuque Formation. Only one fossil site was found in the Skull Ridge Member during our survey and none in the Nambé Member. Both the Skull Ridge and Nambé Members in this area (as mapped by Galusha and Blick, 1971) are composed mostly of "lithosome A" sediments (Koning, 2003) Only the fossils from the Pojoaque Member in the Santa Cruz area are discussed below.

Appendix 1 provides a faunal list of the late Barstovian (medial Miocene) mammals identified from the Pojoaque Member of the Tesuque Formation in the central Española basin, encompassing the Santa Cruz, North Pojoaque Bluffs, and Central Pojoaque Bluffs "fossil-collecting localities" of the Frick Laboratory (Galusha and Blick, 1971, fig. 2, localities 5, 6, 7). The late Barstovian mammal fauna from the Pojoaque Member reviewed by Tedford (1981) and Tedford and Barghoorn (1993) was referred to as the "Santa Cruz sites." However, it is clear from the discussions in these papers that the fauna from the "Santa Cruz sites" was derived not only from the Santa Cruz fossil-collecting locality of Galusha and Blick (1971), as defined above, but also from the North Pojoaque Bluffs and Central Pojoaque Bluffs fossil-collecting localities of the Frick Laboratory. The Pojoaque Bluffs sites (Galusha and Blick, 1971) and the Jacona Microfossil Quarry (Chaney, 2009), as well as the original "Santa Fe marls" sites of Cope (1877), are in the general area of the type section of the Pojoaque Member in the vicinity of the Pojoaque Bluffs (Los Barrancos on the Española 7.5 minute quadrangle), on the Pojoaque and San Ildefonso pueblos and Jacona land grant, about 10-12 km south of the actual Santa Cruz sites.

Taxa in Appendix 1 followed by a superscript [1] are represented by identifiable fossils collected in Arroyo del Llano and Arroyo de Quarteles during our recent BLM survey and are housed in the New Mexico Museum of Natural History (NMMNH) in Albuquerque. Taxa in Appendix 1 followed by a superscript [2] are represented by published fossils from the Pojoaque Member in the Santa Cruz area, mostly collected by Frick Laboratory paleontologists (Joe Rak, John Blick, and Ted Galusha) from First Wash and Second Wash. Taxa followed by a superscript [3] are known from the Pojoaque Bluffs area (North Pojoaque Bluffs and Central Pojoaque Bluffs fossil-collecting localities of the Frick Laboratory), including the Jacona Microfossil Quarry (Chaney, 2009). Taxa in Appendix 1 lacking a superscript number are derived from the Pojoaque Member in the Española basin and are known from the Santa Cruz and/or the Pojoaque Bluffs areas; however, we have not been able to confirm the exact locality data for these taxa from the literature. The taxa lacking superscripts are included in Appendix 1 based primarily on biostratigraphic studies of Miocene mammals from the Española basin (Tedford, 1981; Tedford and Barghoorn, 1993; Tedford et al., 2004) or on mammals reviewed in the various papers in Janis et al. (1998a, 2008). The early late Barstovian locality listed in Janis et al. (1998b, p. 635 and 2008, p. 710) as "SB32D. Pojoaque Member (inc. … Pojoaque Bluffs Area, Santa Cruz Sites, and Jacona Microfossil Quarry)(Ba2)…" actually includes essentially all late Barstovian mammals known from the Pojoaque Member in the Española basin. Thus, for the mammals listed from locality "SB32D" in various papers in Janis et al. (1998a, 2008), we are not able to distinguish taxa listed as coming from the Santa Cruz sites from those derived from Pojoaque Bluffs and other sites in the Pojoaque Member. In some of the taxonomic papers listed below (other than in the Janis et al., 1998a, 2008 volumes), the specific localities for specimens are listed, and we were able to determine which specimens were collected in the Santa Cruz area.

In addition to our recent field survey, the vertebrate faunal list for the Pojoaque Member in the Santa Cruz area comes from a variety of published sources, primarily taxonomic works on various mammalian taxa, including: Erinaceidae (Rich, 1981), Rodentia (Korth and Chaney, 1999; Korth, 2002, 2008), Mustelidae (Baskin, 1998), Ursidae (Hunt, 1998a), Amphicyonidae (Hunt, 1998b), Canidae (Wang et al., 1999; Tedford et al., 2009), Felidae (Rothwell, 2003), Equidae (MacFadden, 1984, 1998), Rhinocerotidae (Prothero, 1998), Oreodontidae (Schultz and Falkenbach, 1941; Lander, 1998), Camelidae (Honey et al, 1998), Dromomerycidae (=Palaeomerycidae of some authors; Frick, 1937; Janis and Manning, 1998a; Prothero and Liter, 2008), Moschidae (Frick, 1937; Webb, 1998; Prothero, 2008), Antilocapridae (Frick, 1937; Janis and Manning, 1998b), and Gomphotheriidae (Frick, 1933; Osborn, 1936; Tobein, 1973; Lambert and Shoshani, 1998).

Paleontologists from the Frick Laboratory (Joe Rak, John Blick, Ted Galusha, and others) made almost yearly field surveys of Miocene vertebrates in the Española basin over 40 years from the mid 1920s to the mid 1960s (Galusha and Blick, 1971; Galusha, 1974). From the late 1970s to the present, field crews from the New Mexico Museum of Natural History and University of New Mexico have conducted periodic surveys of this same region (Kues and Lucas, 1979). Sediments of the Pojoaque Member of the Tesuque Formation in the central Española basin, including the Santa Cruz and Pojoaque Bluffs sites of the Frick Laboratory (Galusha and Blick, 1971), have produced a diverse mammalian fauna numbering at least 65 species (Appendix 1). The intensive field activity in the Española basin over a period of more than 85 years would suggest that the large mammal fauna of the Pojoaque Member is almost completely documented, and that few additional species remain to be discovered. Possibilities for additions to the fauna include uncommon groups currently unrepresented, including chalicotheres (Chalicotheriidae), tapirs (Tapiridae), peccaries (Tayassuidae), and protoceratids (Protoceratidae). Future additions to the faunal list will almost certainly be dominated by small mammals. Only a single diverse microfauna has been reported from the Pojoaque Member, the Jacona Microfossil Quarry (Chaney, 2009). Several other microvertebrate sites are known but inadequately described or sampled, including the Pojoaque Bluffs, the "red layer" in Arroyo de Quarteles (Second Wash), and the "green layer" in Arroyo de la Morada (Third Wash). Ongoing field studies of the Pojoaque Member by NMMNH crews are focusing on the recovery of additional microvertebrate faunas. Overall, nearly a third of the mammalian taxa on the faunal list are identified only to the genus level. In most cases, this results from the lack of modern taxonomic studies of these groups, not an absence of adequate fossil material.

The Pojoaque Member also has a rather diverse lower vertebrate fauna composed of amphibians (frogs, toads, and salamanders), reptiles (land tortoises, freshwater turtles, snakes, and lizards), and a variety of birds. Lower vertebrates are not included in Appendix 1 because there are only a limited number of taxonomic studies of these groups in the Española Basin, and thus very few taxa have been identified below the family level. Moreover, unlike mammals, most Miocene lower vertebrates are not age diagnostic. Among lower vertebrates from the Pojoaque Member, the most commonly encountered in the field are medium to large tortoises of the genus *Hesperotestudo*, some with shells nearly a meter in length (Sena and Thomas, 1989). Chaney (2009) listed a wide range of amphibians, reptiles, and birds from the Jacona Microfossil Quarry, most identified only to the family level, including frogs/toads, salamanders, anguid lizards, colubrid and viperid snakes, and at least seven birds, including ducks (Anatidae), hawks (Accipitridae), quail (Tetraoninae), rails (Rallidae), owls (Strigidae), woodpeckers (Picidae), and perching birds (Passeriformes).

The following is a brief summary of the mammalian biostratigraphy of the Pojoaque Member in the central Española Basin, based on data from our field work and biostratigraphic studies by Tedford (1981), Tedford and Barghoorn (1993, 1997), and Tedford et al. (2004). The most age-diagnostic mammal in the Pojoaque Member is the gomphotheriid proboscidean *Gomphotherium productum*. The first appearance of proboscideans in North America as immigrants from Eurasia has been termed the "Proboscidean Datum" and occurred in the early medial Miocene (early late Barstovian) between about 14.5 and 14.8 Ma (Woodburne and Swisher, 1995; Tedford et al., 2004). Although there are rare records of proboscideans from the late early Miocene (late Hemingfordian NALMA) and earliest middle Miocene (early Barstovian NALMA) elsewhere in North America (e.g., Prothero et al., 2008), no proboscidean fossils have ever been found in the late Hemingfordian Nambé Member or early Barstovian Skull Ridge Member in the Española Basin. *Gomphotherium productum* is common in the Pojoaque Member, including a complete skull collected in 1988 (Heckert et al., 2000) and the associated mandibles of this same individual (NMMNH 28972) collected more than 20 years later during our current survey, from about 100 m above the base of the member in Arroyo del Llano (Fig. 2). The first appearance of several other mammals defines the late Barstovian (Ba2), including the following mammals known from the Pojoaque Member: the erinaceid hedgehog *Untermannerix*, the amphicyonid bear dog *Pseudocyon*, the mephitid carnivore

Pliogale, and the ocotonid lagomorphs *Hesperolagomys* and *Russellagus* (Rich, 1981; Hunt, 1998b; Tedford et al., 2004; Chaney, 2009). We collected a lower jaw of *Pliogale nambiana* (NMMNH 63415) during our survey, near the top of the Pojoaque Member just below the Cejita Member (Fig. 2). Other mammals known from the Pojoaque Member that also have their earliest occurrence in the late Barstovian include: the borophagine canids *Aelurodon ferox* and *A. stirtoni*, the three-toed horse *Neohipparion coloradense*, the oreodont *Merychyus medius*, the camelid *Procamelus*, the moschid ruminant *Longirostromeryx*, and the antilocaprid *Ramoceros*. During our survey, we collected a mandible (NMMNH 63412) and lower first molar (m1) of *Aelurodon ferox* (NMMNH 57620), both also from high in the Pojoaque Member. A partial skull, lower jaws, and partial postcranial skeleton of *Neohipparion coloradense* (NMMNH 63417), was found about 80 m above the base of the Pojoaque Member. Other mammals from the Pojoaque Member that are typical of, but not limited to, the late Barstovian, include: the primitive bear *Hemicyon* (*Plithocyon*) *ursinus*, the small felid *Pseudaelurus stouti*, the fox-like canid *Leptocyon vafer*, the beaver *Monosaulax pansus*, the cricetid rodent *Copemys loxodon*, the large anchitheriine horse *Megahippus mckennai*, the dromomerycid artiodactyl *Cranioceras teres*, and the antilocaprid *Meryceros crucensis*. We found mandibles of *Pseudaelurus stouti* (NMMNH 63413), *Leptocyon vafer* (NMMNH 63414), and *Copemys loxodon* (NMMNH 63416), and a horn core of *Meryceros crucensis* (NMMNH 57608) during our recent survey. The stratigraphic position of several of these species in the Pojoaque Member is indicated in Fig. 2. The fossil mammals from the Pojoaque Member represent one of the most important samples of early late Barstovian mammals in western North America, dating to the interval between about 14.5 and 13.3 Ma (Tedford, 1981; Tedford and Barghoorn, 1993; Tedford et al., 2004), which supports the age range of this unit indicated by the Pojoaque white ash zone (14.0-13.2 Ma) as discussed above.

It is always preferable to determine biostratigraphic intervals based on the presence of taxa rather than their absence because there are many factors besides age that may result in taxa being absent from a particular fauna, including paleoecology, taphonomy, biogeography, and others. Nonetheless, in very well-sampled geologic units in which hundreds, if not thousands of fossils have been collected, such as the Pojoaque and Skull Ridge Members, both the presence and absence of taxa have biostratigraphic significance. Thus, the lack of Proboscidea in the Skull Ridge Member almost certainly reflects a true absence of this group, especially considering the abundance of *Gomphotherium* in the overlying Pojoaque Member. Conversely, it is also significant that several age-diagnostic genera of mammals have their last appearance in the Skull Ridge Member (early Barstovian, Ba1) and are absent from the Pojoaque Member, including: the large amphicyonid *Amphicyon*, the anchitheriine horse *Anchitherium*, the oreodont *Brachycrus*, the youngest stenomyline camel *Rakomylus*, and the dromomerycid artidodactyls *Dromomeryx* and *Rakomeryx*.

CONCLUSIONS

The southeastern part of the study area is very fossil rich. These fossils are all found within sediments containing a mixture of Paleozoic and Proterozoic clast types ± Cenozoic volcanic clasts. Sediments composed of only Proterozoic clast types did not yield any fossil material. The fossils are late Barstovian in age based on the concept of North American land mammal "ages" (Tedford and Barghoorn, 1993; Tedford et al., 2004) and the majority of the fossils are within the Pojoaque White Ash Zone, which is 13.2-14.0 Ma (Koning, 2003). Diagenetic conditions after burial likely had a significant effect on preservation of bone in the study area, but the specific depositional environment and rate of deposition may have also been significant factors.

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APPENDIX 1. Mammalian faunal list from the middle Miocene (late Barstovian) Pojoaque Member, Tesuque Formation, Española basin, northern New Mexico.

Mammalian Fauna	**References**
Lipotyphla	
Erinaceidae	
Metechinus amplior[2]	Rich (1981)
Untermannerix copiosus[2,3]	Rich (1981)
Talpidae	
Achlyoscapter?[3]	Chaney (2009)
Gaillardia sp.[3]	Chaney (2009)
Mystipterus sp.[3]	Chaney (2009)
Scapanoscapter?[1,3]	Chaney (2009)
Soricidae	
Adeloblarina sp.[3]	Chaney (2009)
Alluvisorex sp.[3]	Chaney (2009)
Limnoecus sp.[3]	Chaney (2009)
Rodentia	
Mylagaulidae	
Mylagaulus laevis[3]	Chaney (2009)
Sciuridae	
Tamias sp. [1,3]	Chaney (2009)
Spermophilus sp. [1,3]	Chaney (2009)
cf. *Petauristodon* sp.	Chaney (2009)
Heteromyidae	
Mioperognathus willardi[3]	Korth (2008)
Geomyoidea	
Subfamily Mojavemyinae	
Mojavemys galushai[3]	Korth & Chaney (1999)
Phelosaccomys neomexicanus[3]	Korth & Chaney (1999)
Castoridae	
Monosaulax pansus[1,2,3]	Cope (1877), Korth (2002), Chaney (2009)
Zapodidae	
Plesiosminthus sp.[3]	Chaney (2009)
Cricetidae	
Copemys loxodon[1,3]	Cope (1877), Chaney (2009)

APPENDIX 1. (cont.)

Mammalian Fauna	**References**
Lagomorpha	
Ochotonidae	
Hesperolagomys sp.[3]	Chaney (2009)
Russellagus sp.[3]	Chaney (2009)
Leporidae	
Hypolagus sp.[1,3]	Chaney (2009)
Panolax sanctaefidei[3]	Cope (1877), White, (1987), Chaney (2009)
Carnivora	
Procyonidae	
Bassariscus sp.[3]	Chaney (2009)
Mustelidae	
Pliogale nambiana[1,3]	Cope (1877), Baskin (1998)
Ursidae	
Plithocyon (=*Hemicyon*) *ursinus*[3]	Frick (1926), Hunt (1998a)
Amphicyonidae	
Pseudocyon sp.[3]	Hunt (1998b)
Canidae	
Borophaginae	
Aelurodon ferox[1,2,3]	Wang, Tedford & Taylor (1999)
Aelurodon stirtoni[2]	Wang, Tedford & Taylor (1999)
Carpocyon webbi[2,3]	Wang, Tedford & Taylor (1999)
Epicyon saevus[2]	Wang, Tedford & Taylor (1999)
Paratomarctus temerarius[2,3]	Wang, Tedford & Taylor (1999)
Caninae	
Leptocyon vafer[1,2,3]	Tedford, Wang & Taylor (2009)
Felidae	
Pseudaelurus marshi[1,2]	Rothwell (2003)
Pseudaelurus stouti[1,2]	Rothwell (2003)
Perissodactyla	
Equidae	
Anchitheriinae	
Hypohippus sp.	MacFaddden (1998)
Megahippus mckennai	MacFaddden (1998)
Equinae: Hipparionini	
Cormohipparion sp.	MacFaddden (1998)
"*Merychippus*" *calamarius*	MacFaddden (1998)
Neohipparion affine	MacFaddden (1998)
Neohipparion coloradense[1]	MacFaddden (1998)
Equinae: Equini	
Pliohippus supremus	MacFaddden (1998)
Rhinocerotidae	
Aphelops megalodus	Prothero (1998)
Peraceras hessei	Prothero (1998)
Peraceras profectum	Prothero (1998)
Peraceras superciliosum	Prothero (1998)
Teleoceras new sp.	Prothero (1998)
Artiodactyla	
Oreodontidae	
Merychyus medius[1,2,3]	Schultz & Falkenbach (1941), Lander (1998)
Camelidae	
Miolabinae	
Miolabis sp.	Barghoorn (1985), Honey et al. (1998)
Nothotylopus sp.	Barghoorn (1985), Honey et al. (1998)
Paramiolabis sp.	Barghoorn (1985), Honey et al. (1998)
Protolabinae	
Michenia sp.	Barghoorn (1985), Honey et al. (1998)
Protolabis sp.	Barghoorn (1985), Honey et al. (1998)

APPENDIX 1. (cont.)

Camelinae: Camelini	
Procamelus sp.	Barghoorn (1985), Honey et al. (1998)
Camelinae: Lamini	
Aepycamelus sp.	Barghoorn (1985), Honey et al. (1998)
Camelinae: incertae sedis	
Australocamelus sp.	Barghoorn (1985), Honey et al. (1998)
Leptomerycidae	
Pseudoparablastomeryx francescita	Frick (1937), Taylor & Webb (1976), Webb (1998)
Moschidae	
Blastomeryx francesca	Frick (1937), Webb (1998), Prothero (2008)
Longirostromeryx blicki[2,3]	Frick (1937), Webb (1998), Prothero (2008)
Dromomerycidae (=Palaeomerycidae)	
Cranioceras teres[2,3]	Cope (1877), Frick (1937), Janis & Manning (1998a), Prothero and Liter (2008)
Antilocapridae	
Meryceros crucensis[1,2,3]	Frick (1937), Janis & Manning (1998b)
Meryceros major	Frick (1937), Janis & Manning (1998b)
Plioceros blicki	Frick (1937), Janis & Manning (1998b)
Ramoceros marthae	Frick (1937), Janis & Manning (1998b)
Ramoceros ramosus[2,3]	Frick (1937), Janis & Manning (1998b)
Submeryceros crucianus[2]	Frick (1937), Janis & Manning (1998b)
Proboscidea	
Gomphotheriidae	
Gomphotherium productum[1,2,3]	Cope (1877), Tobien (1973)
Megabelodon joraki	Frick (1933), Lambert & Shoshani (1998)

Notes:
Only taxa identified to the genus or species level are included on this list. Taxa followed by a superscript ([1]) were found in Arroyo del Llano and/or Arroyo de Quarteles during our recent survey. Taxa followed by a superscript ([2]) were collected by the Frick Laboratory from the Santa Cruz fossil-collecting locality, mostly from First Wash (=Arroyo del Llano) and Second Wash (=Arroyo de Quarteles). Taxa followed by a superscript ([3]) are known from the Pojoaque Bluffs area (North Pojoaque Bluffs and Central Pojoaque Bluffs fossil-collecting localities of the Frick Laboratory), including the Jacona Microfossil Quarry (Chaney, 2009). Unmarked taxa are derived from the Pojoaque Member in the Española basin and are known from the Santa Cruz and/or the Pojoaque Bluffs areas; however, we have not been able to confirm the exact locality data for these taxa from the literature (e.g., Tedford, 1981; Tedford and Barghoorn, 1993; various papers in Janis et al., eds., 1998a). References for the identifications of mammals from the Pojoaque Member are listed for each genus/species.


AN ODE TO KYANITE
It is possible that I am pushing through solid rock,
like a vein of ore, encased.
And I am so far in, I see no end,
and no distance: everything is close to my face,
and everything close to my face is stone.
I am not yet wise in grief-
so this great darkness makes me small.
But if it's you: make yourself fierce, break in:
Then your great transforming will happen to me,
and to you, the fullness of my cry.
- Rainer Maria Rilke
mary simmons