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SUMMARY OF THE PALEONTOLOGY OF THE SANTA FE GROUP (MIO-PLIOCENE), NORTH-CENTRAL NEW MEXICO

BARRY S. KUES
Department of Geology
University of New Mexico
Albuquerque, New Mexico 87131
and
SPENCER G. LUCAS
Department of Geology and Geophysics, and Peabody Museum of Natural History
Yale University
New Haven, Connecticut 06520

INTRODUCTION

The Santa Fe Group, as restricted by Galusha and Blick (1971) to rocks of the type and contiguous areas, crops out extensively in and around the Rio Grande valley from Santa Fe northward past Espanola to beyond Abiquiu and Ojo Caliente (fig. 1). Strata lithologically and temporally equivalent to those present in the type area also are exposed south of Santa Fe (Kelley, 1977; Kelley and Northrop, 1975), but will not be considered in this report. Deposition of the Santa Fe Group extended from late Hemingfordian (medial Miocene) to Hemphillian (early Pliocene) time (Galusha and Blick, 1971; Mac Fadden, 1977), a period of about 12 million years. Characteristic Santa Fe exposures are buff, brown, red, gray or green colored shales, sandstones and conglomerates that contain numerous white ash layers and erode into highly dissected expanses of badlands. From these beds has come one of the most abundant, diverse and continuously sampled vertebrate faunas in the world; the Santa Fe Group is arguably the most thoroughly and carefully collected stratigraphic unit in New Mexico. The purposes of this paper are to summarize briefly the paleontology of the Santa Fe, to describe the nature of fossil collections and work in progress, and to suggest areas of profitable future research.

PALEONTOLOGY

History of Study

Vertebrate fossils from the Santa Fe first were collected and described by E. D. Cope in the 1870's (e.g., Cope, 1874a). Although most of the fossils he collected were fragmentary, they included many new species. Little paleontological activity followed Cope's efforts until Childs Frick became interested in these fossils and sponsored an exploratory collecting expedition in the summer of 1924. In less than a week, a complete skeleton of the "dog-bear" *Hernicyon* had been discovered (Frick, 1926c, p. 447), and the remains of other fossil vertebrates proved to be so varied and abundant that Frick, in association with the American Museum of Natural History, began a collecting program that ran nearly continuously for 40 years. During this time, all Santa Fe exposures in the Espanola basin and "Abiquiu re-entrant" (Galusha and Blick, 1971) were prospected for fossils, and many productive localities and horizons were visited many times. Such a concentrated collecting effort allowed the most fossiliferous beds to be periodically and thoroughly sampled before surface accumulations could be fragmented by erosion, and insured that most exposed concentrations of bone were discovered. Most fossils proved to

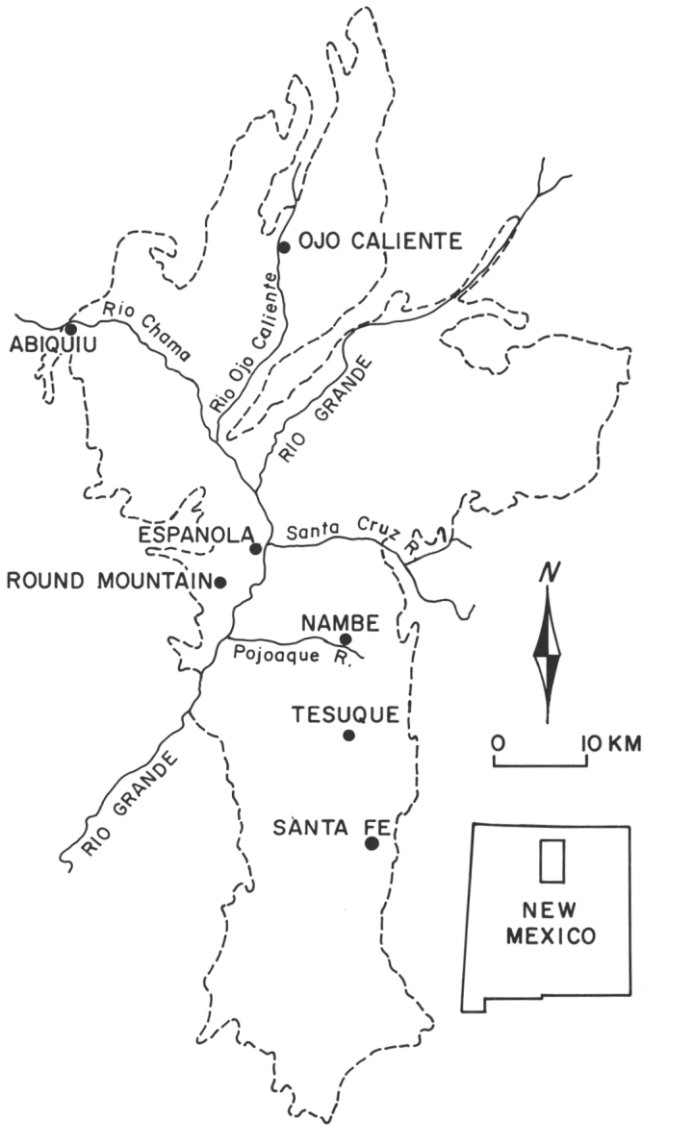

Figure 1. Location of type Santa Fe Group exposures (dashed line), the area from which most of the Santa Fe vertebrate fossils have been collected.

be isolated bones or skeletons, but more than a dozen dense concentrations of numerous individual animals were found and quarried. The largest of these quarry operations was on the south side of Round Mountain (fig. 1) where several hundred large crates of bone were excavated in 1935 and 1936; large piles of debris are still visible there. The Frick/American Museum program ceased in 1965, and with the exception of the Chamita Formation (Mac Fadden, 1977), relatively little additional sampling of the Santa Fe Group has been accomplished. A University of New Mexico survey of selected areas around Espanola in the summer of 1978 revealed that excellent skeletal remains have eroded out in some places since 1965 (Kues and others, 1978).

Nature of Fauna

Santa Fe fossils are mainly vertebrates; plants and invertebrates are rare and also have not been collected as intensively as the vertebrates. Because only some of the vertebrate groups have been studied and no complete census of the vast American Museum collections has been made, it is not possible to present more than a general summary of the major constituents of the Santa Fe faunas (e.g., Galusha, 1974). Information on the relative abundance of the various groups in each stratigraphic subdivision of the Santa Fe would be informative, but will not be available until the entire collection is studied. Nevertheless, some indication can be given for the Santa Fe Group as a whole.

In the period 1942-1965, approximately 10,000 major skeletal elements (bones, teeth, horns, etc.) were collected from the Espanola area (Kues and others, 1978, p. 96); the number collected before 1 942 undoubtedly exceeds this total. About 29% of the post-1941 fossils are camels, 19% are "deer," and 13% are horses. Rodents (excluding beavers), "Carnivora" only identified to the ordinal level, and antilocaprids each comprise between 5 and 10% of the faunas, and rhinoceroses, gomphotheres, oreodonts, dogs, bears and "dog-bears" each represent 1 to 5% of the total. Vertebrates present in smaller numbers include beavers, rabbits, shrews, hedgehogs, moles, peccaries, sloths, cats, weasels, birds, frogs, lizards and tortoises. In almost all of these groups, several genera are represented, as would be expected in a unit that spanned over 10 million years. A total of about 110 vertebrate species has been recognized in the Santa Fe Group collections, and the list will grow as work on these fossils proceeds. It should be pointed out that the percentages given above are intended only as a gross estimate of relative abundances of collected fossils; they have little or no significance with respect to the composition of the succession of paleocommunities that existed in northern New Mexico during Mio-Pliocene time.

From the above, it is obvious that large mammals dominate the collections of Santa Fe fossils. While it is undoubtedly true that great numbers of these animals existed during the time of Santa Fe deposition, a collecting bias towards the larger animals also contributes to their over-representation. Of the most common mammals, camels are represented by at least 12 species that encompass forms ranging from the size of gazelles to some that were nearly the size and dimensions of giraffes. Many of the "deer" are representatives of relatively primitive groups that since have become extinct or given rise to modern forms. A wide variety of horn types characterizes these mammals, and horns are among the most frequently found of their remains.

The horses of the Santa Fe Group were somewhat smaller than modern horses and possessed three toes on each foot. Oreodonts were a very successful group of grazing animals, perhaps best visualized as having a combination of pig and small-camel features. Although oreodonts were once the most abundant mammal in North America, by the middle Miocene, they had passed the peak of their success, and they represent but a small part of the vertebrate fauna of the Santa Fe Group. Some of the last surviving members of this extinct group are found in the Pliocene part of the Santa Fe. The largest of the Santa Fe mammals were the gomphotheres, extinct predecessors of modern elephants that possessed tusks in the lower as well as upper jaw. Several types of rhinoceros also are present in the Santa Fe, including *Teleoceras,* a presumably amphibious genus with short legs and a stout body reminiscent of the modern hippopotamus.

Carnivorous mammals are not as abundant as the large herbivores discussed above, but are highly diverse. Some forms were similar to modern dogs, foxes, cats, raccoons, badgers, skunks and weasels, but groups now extinct were present as well. Most Santa Fe cats, for example, possessed enlarged canine teeth that would qualify them as "saber-toothed," and there was a large variety of bulky dog-like carnivores, some of which were probably close to the ancestry of bears.

In summary, the Mio-Pliocene faunas of north-central New Mexico contain a mixture of essentially modern mammals, primitive representatives of some modern groups, and unfamiliar groups now extinct. The great differences between the geologically young Santa Fe faunas and modern North American faunas can be illustrated by pointing out that almost all of the dominant herbivores of the Santa Fe, such as camels, horses, rhinoceroses, gomphotheres and oreodonts, have disappeared from North America in the 4-5 million years since the last Santa Fe deposits were laid down.

Status of Collections

Most of the enormous number of fossils collected from the Santa Fe Group is housed in the Frick wing of the American Museum of Natural History in New York; many of the most complete and impressive specimens are on display in the main American Museum galleries. Not surprisingly, the collection of fossils far exceeded the rate at which they have been curated and studied. About 30% of the specimens have been formally catalogued into the American Museum collections; much of the collections are still in storage and have yet to be examined in detail.

The degree of scientific attention that has been focused on the Santa Fe vertebrates varies considerably from group to group. Some taxa originally established by Cope were based on fragmentary remains and are not easily recognizable today. A list of published taxonomic reports on vertebrates from the Santa Fe Group is given in Table 1. Groups currently being studied, mainly by American Museum paleontologists, are canids, felids, rodents (including especially beavers), some camels and Pojoaque Member micro-vertebrate remains (R. H. Tedford, personal commun., 1978). Rhinoceroses, peccaries, insectivores and rabbits generally have not been studied intensively yet. In addition, there is a need for revision of some of the earlier published works.

One suggestion of the richness and paleontologic importance of the Santa Fe faunas is the number of complete or nearly complete skeletons that have been excavated. Verte-

Table 1. A list of the major publications in which vertebrate taxa from the Santa Fe Group have been described or illustrated. Preliminary faunal lists and reviews of all or part of the Santa Fe vertebrates have been given by Cope (1877), Matthew (1899, 1909), Stirton (1936), Simpson (1950), Galusha and Blick (1971), Galusha (1974) and MacFadden (1977).

TAXA	PUBLICATIONS
Class Reptilia	
Order Testudines	
tortoises	Cope (1875a), Hay (1908), Williams (1950)
Class Aves	
Order Falconiformes	
vultures	Cope (1847a,b; 1875d), Brodkorb (1964)
Class Mammalia	
Order Edentata	
sloths	Hirschfeld and Webb (1968)
Order Lagomorpha	
rabbits	Cope (1874a,b), Dawson (1958)
Order Rodentia	
beavers	Cope (1875b), Stirton (1935)
cricetids	Cope (1874a,b), Wood (1936)
Order Carnivora	
"dog-bears"	Frick (1926a), Vanderhoof and Gregory (1940), Colbert (1941)
mustelids	Cope (1874a,b), Hall (1930)
Order Proboscidea	
gomphotheres	Leidy (1873), Cope (1875b,e), Frick (1926b; 1933), Osborn (1936)
Order Perissodactyla	
horses	Cope (1875a,c), Osborn (1918), Stirton (1940)
rhinoceroses	Cope (1875a,c), Matthew (1932)
Order Artiodactyla	
oreodonts	Thorpe (1937), Schultz and Falkenbach (1940, 1941, 1947, 1968)
camels	Cope (1875a,c), Frick (1937), Frick and Taylor (1968, 1971)
"horned ruminants" (i.e., cervids, antilocaprids, bovids, protoceratids and hypertragulids)	Cope (1874a,b; 1876), Frick (1937), Taylor and Webb (1976)

brate skeletons, composed of many separate bones, rarely endure the dispersive effects of scavengers, preburial transport and erosional destruction after fossilization. In the Santa Fe Group from 1924 to 1965, about 180 complete or partial skeletons were collected, about 60% of these being camels. The great abundance, diversity and quality of preservation of the Santa Fe faunas, even though they are incompletely studied, have allowed precise relative ages to be assigned to the various members of the Santa Fe Group (Galusha and Blick, 1971); study of the magnetostratigraphy (MacFadden, 1977) and radiometric ages of volcanic layers within the Santa Fe (Manley, 1979) will further extend and refine our understanding of the timing of various phases of Santa Fe deposition.

Paleoenvironment

The variety of facies, lithologies and source areas for Santa Fe Group deposits has been documented in detail by Galusha and Blick (1971), Kelley and Northrop (1975), Kelley (1977) and others. Santa Fe sediments were derived from source areas marginal to the Rio Grande trough, such as the Sangre de Cristo and San Juan mountains, as well as from active local volcanism. Most Santa Fe sediments were deposited as alluvial fans, distributary channels lateral to and between fans, or in association with a wide range of basinal fluvial conditions.

The large numbers of large fossil vertebrates preserved in the Santa Fe include types that formed herds (horses, camels, antilocaprids, rhinoceroses and oreodonts), and suggest a climate conducive to the growth of extensive and diverse floras. This suggestion is reinforced by the abundance of both browsing and grazing mammals. Kelley and Northrop (1975, p. 69) interpreted the climate that prevailed during Santa Fe deposition south of the type area to be "warm and humid to savannah-type conditions" on the basis of the pinkish terra cotta to light gray colors of subaerially weathered sediments. Unfortunately, identifiable plant fossils that might provide detailed paleoclimatic information are very sparse in the Santa Fe Group. Axelrod (1975) and Axelrod and Bailey (1976) reported a fossil palm from the Tesuque Formation a few kilometers northwest of Santa Fe, indicating a mean average temperature of 15-17°C (about 7°C warmer than today's mean temperature for this area) and an annual range in temperature considerably less than today's. Winter climates were interpreted as being mild and almost frostless, mainly because the average elevation of the Santa Fe area is believed to have been over 1000 meters lower in the Miocene than it is now (Axelrod and Bailey, 1976). Local episodes of aridity seem indicated by the presence of eolian sands (0jo Caliente Member, Tesuque Formation) within the Santa Fe Group (Galusha and Blick, 1971, p. 69, 117).

Judging from the abundant ash beds and the local presence of volcanic clasts and small lava flows, volcanism was a significant environmental factor during Santa Fe deposition. Fossils are extremely rare in the ash beds, suggesting that ash falls were not dense or fast enough to prevent the vertebrate populations from migrating to other areas during a fall, and then returning after it was over, instead of being catastrophically inundated. Galusha and Blick (1971, p. 57) suggested that increased rainfall would accompany the injection of volcanic ash into the atmosphere and cause ephemeral ponding or flooding over areas receiving the ash falls. As lacustrine sedimentary structures and fish fossils are absent, permanent lakes or ponds apparently were not present during the time of Santa Fe deposition.

In light of the above, the environment of north-central New Mexico during the middle Miocene to early Pliocene may be visualized as one of savannah-like plains in areas of low relief, with more luxurious vegetation along perennial streams and tributaries, and with forests that conceivably characterized higher elevations. Petrified wood is locally common in the Santa Fe, indicating the presence of at least some forests. Horses, antilocaprids, oreodonts and some camels and rhinoceroses, along with varied carnivores, rodents and tortoises would have been the most conspicuous inhabitants of the savannahs, while local forested areas within the savannahs and along streams would have been the habitat of browsing mammals such as gomphotheres, "deer" and rhinoceroses. In for-

ests near streams, beavers, rhinoceroses like *Teleoceras,* shrews, some rodents and smaller carnivores such as skunks, martens, raccoons and weasels would have been found. The climate was generally warm, more humid than today, and winters were mild. Different communities of vertebrates, some very diverse and with relatively high biomass, existed in several different vegetational regimes and at different elevations, although vertical faunal and floral variations were probably not as pronounced as they are in this area today.

The Future

Even with the careful, nearly continuous and intensive collecting effort maintained by the American Museum over 40 years, much work remains to be done on the paleontology of the Santa Fe Group. Precise localities for many of the fossils collected in the 1920's and 1930's are either not available or are buried in the letters and field books of the early collectors. Until relatively recently, accurate topographic maps were not available, and it was not customary to precisely designate each fossil locality. Relocation of these early localities will allow the bulk of these fossils to be integrated into the detailed rock-stratigraphic framework now available (and being restudied) for the Santa Fe Group, so that the succession and distribution of faunas may be known better. Taxonomic description and study of some groups remain to be done, and additional sampling of small vertebrates, which are underrepresented in present collections, using methods such as screen-washing, could provide much new information on Santa Fe faunas. Definition and study of the structure, composition and evolution of paleocommunities through the time represented by Santa Fe deposition would be a complex but feasible endeavor, but must wait until systematic studies of most groups are completed. Significant fossils continue to erode out of Santa Fe beds in some areas; a periodic "harvesting" of these fossils will augment collections previously made and provide more information on population structure and intraspecific variability of the taxa represented.

Santa Fe fossils, particularly in exposures around Espanola, are being subjected to the impacts of rapid population growth, and the consequent possibility of destruction of specimens or their removal from scientific scrutiny by uninformed amateur collectors. Additional collecting and study of Santa Fe fossils by paleontologists are warranted, and careful consideration by land-managing agencies of the impact of new land-use activities on Santa Fe fossils will help to preserve paleontological information and extend our knowledge of the diverse and abundant organisms that lived in Santa Fe country 5 to 17 million years ago.

ACKNOWLEDGMENTS

We thank Drs. R. H. Tedford and M. C. McKenna for permission to examine the collections and records of the Frick collection of vertebrate fossils at the American Museum of Natural History, and other American Museum personnel, especially Earl Manning, for their help. We also thank Mary Ann Turner and Mahmood Raza of Yale University for helpful criticism of the manuscript. Some of the information presented here was assembled under a contract with the U.S. Bureau of Land Management.

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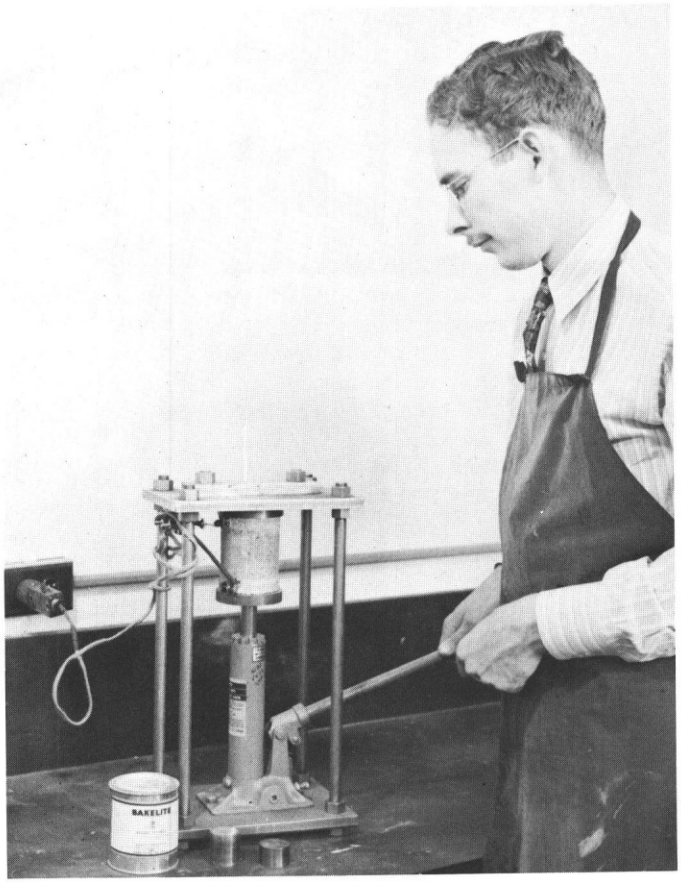
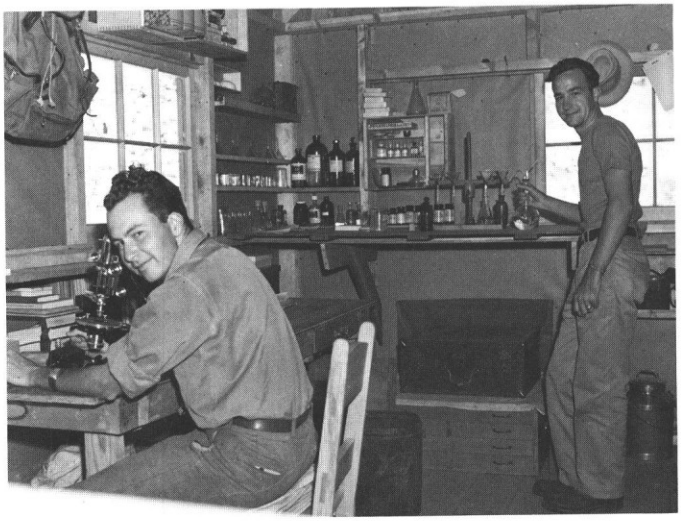


Gordon H. Wood, then a senior, University of New Mexico, 1941, and formerly Chief, Branch of Coal Resources, Office of Energy Resources, USGS, Reston, Virginia, with Bakelite mounting press used for making briquettes.—V. C. Kelley.

Lauren Wright, Frank Rutledge and Ian Campbell, then at Caltech, later State Geologist of California, at Iron Mountain, New Mexico, 1943.—R. H. Jahns.



Lauren Wright and Porter Irwin (both USGS) in the temporary laboratory set up in the office at the Harding mine, 1943. The lab was used to make quantitative analyses of U.S. Bureau of Mines drill cores, mainly for Be, Li and Ta content.—R. H. Jahns.

A friendly little game in the cook house, Iron Mountain, New Mexico, 1942. Frank Rutledge (USBM project engineer), Mike Montoya (USBM blacksmith and miner), Lauren Wright (USGS), Joe Trujillo (USBM miner), Sofia Samora (USBM miner and assistant cook), and George Bricourt (USBM cook).—R. H. Jahns (See article and stops on November 12, 1955 road log by Jahns.)