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PALEONTOLOGICAL SURVEY
San Juan Planning Unit
and
Rio Puerco Resource Area

PART I
Report of Investigations

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PALEONTOLOGICAL SURVEY OF THE SAN JUAN PLANNING UNIT AND THE RIO PUERCO RESOURCE AREA

Part I

Report of Investigations

By

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and

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Bureau of Land Management
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INTRODUCTION

The objective of this report is to provide an evaluation of the scientific and cultural value of the paleontological resources of the San Juan Planning Unit (Fig. 1) and Rio Puerco Resource Area of northwestern New Mexico (Fig. 13). It is based on previously published and unpublished work in these area and on a field survey carried out in conjunction with this project. The report is divided into two parts: the first part contains a report on the San Juan Planning Unit and the Rio Puerco Resource area, and the second contains an annotated bibliography of the paleontological literature of both areas.

Methods

A large part of each study area is underlain by rocks which rarely contain significant fossil material. These include Quaternary alluvium and terrace gravels, Tertiary basalt and thick beds of sandstone and conglomerate of the San Jose Formation such as occur in the vicinity of Navajo Reservoir. As shown in Table 1, such rocks cover about 1500 square miles (71%) of the San Juan Planning Unit and about 400 square miles (35%) of the Rio Puerco Resource Area. Since it was obvious that the chances of making any important finds in these rocks were poor, we devoted our fieldwork to those offering better potential. In essence, we concentrated our efforts on about 550 square miles in the San Juan Planning Unit and 675 square miles in the Rio Puerco Resource Area, a total of about 1200 square miles.

At the beginning of the project, it was recognized that an intensive survey of all the outcrops in these 1200 square miles of the two areas would be impossible in the time available. For example, the entire time could have been spent in the huge amphitheater of Nacimiento Formation

Table 1

Approximate areas of outcrops of units likely and unlikely to contain fossils in the study area (in square miles)

Units	SJPU	RPRA
Units unlikely to contain fossils		
Quaternary alluvium, and terrace gravel.	527	309
Tertiary basalt.		56
Poor exposures and thick sandstone beds of the San Jose Formation	1010	57
Totals	1537	422
Units likely to contain fossils	563	678
Totals	2100	1100

badlands in Kutz Canyon alone. In view of this, two levels of survey effort and two priority levels were established to provide a framework within which to work. This insured that an adequate field survey of the areas was completed to complement the literature search. Levels of survey effort were:

(1) Reconnaissance--our team drove most or all roads, examined known fossil localities (if any), recorded outcrops on available topographic maps, and spot-checked some of these exposures on foot. Interior areas inaccessible by road were not examined nor were general collections made.

(2) Survey--our teams walked an area, staying within visual contact, and surface collected. Areas inaccessible by road were explored, and general collections made, but significant amounts of time were not spent at any given site. However, an effort was made to secure against erosion important specimens that were not too large or fragile to collect without a large expenditure of time.

The priority of an area determined whether reconnaissance or survey (or both) of the area was undertaken. The two levels of priority were:

(1) Priority 1--Of highest priority in this survey were designated "critical areas" under control of the Bureau of Land Management that face a high possibility of intense land use in the near future. Somewhat more survey time (perhaps 10%) was devoted to these areas than to others.

(2) Priority 2--Outcrops outside the critical areas but within the study areas were considered to be of secondary importance. Those priority 2 outcrops with known fossil localities and those previously surveyed by the University of New Mexico team (Kues et al., 1977) received only cursory survey (Reconnaissance plus some walking of exposures) in order to verify the presence of the localities and determine whether or not new fossil material has recently eroded out onto the surface.

Throughout the survey and compilation of this report, a heavy reliance was placed on the report by Kues et al. (1977). The three major reasons for this are:

1. The Kues et al. report is a comprehensive compendium of knowledge about the paleontological resources of the San Juan Basin, including much of the SJPU and RPRA. As such, it forms a primary source from which to further investigate the literature on San Juan Basin paleontology.

2. This report also contains much useful discussion and summarization of information on the paleontology of the SJPU and RPRA which forms in some areas the most concise and accurate summary of existing knowledge. In addition the report contains information on previously known collecting areas and localities in the SJPU and RPRA, as well as, the extent and disposition of a large amount of the fossil material collected at these localities and now stored in various museums all over the country.

3. Throughout our work under this contract our policy has been to avoid duplication of effort wherever possible, because time is of the essence. It would seem neither time efficient nor cost efficient to duplicate information on the paleontological resources of an area that has already been adequately and recently presented to the Bureau of Land Management by previous report(s). In addition, discussions with several people now* (or recently) carrying on research on fossils in the San Juan Basin have confirmed the accuracy of much of the information presented in the Kues report.

*e.g., Costas Tsentas (New York Univ.), Glen Conroy (Brown Univ.), Thomas Lehman (Univ. of Texas), etc.

Furthermore, our own field observations have also confirmed its veracity.

In short, our reliance on the Kues et al. (1977) report is based both on our efforts to avoid duplication of effort because of time and financial constraints as well as our judgment that the report provides an adequate and accurate assessment of the paleontological resources in those areas surveyed by the University of New Mexico team.

At several places in this report we use the term "qualified paleontologist." We define a qualified paleontologist to be a person who has a Bachelors degree in botany, zoology or geology and at least a Masters degree in paleozoology or paleobotany or has had equivalent appropriate research and/or field experience in the subject.

Discussion

During the course of our survey, 191 localities were discovered. In such a large area, some 1200 square miles this number of localities might, at first glance, appear to be very small. However, there are two good reasons for this.

First our collector's were instructed to look for material of good quality and not to designate a locality unless they judged the material to be identifiable to at least the generic level. The judgment of what is generically identifiable, of course, varies, depending on the experience and expertise of the collector as well as the nature, preservation and occurrence of the fossil material. (It is obviously more difficult to macroscopically assess whether or not petrified wood is generically identifiable than it is to make a comparable assessment of fossil mammal teeth. The isolated fragments of dinosaur bone weathering down a slope may be generically indeterminate, but the partial skeleton buried under the slope from which they came may be identifiable. An assessment of such a find is often very difficult to make quickly in the field.) We, thus, instructed our collectors to be selective. A walk through almost any series

of outcrops of many units exposed in the RPRA and SJPU reveals numerous and scattered remains of everything from hunks of abraded petrified wood to scraps of turtle shell. Without a certain amount of selectivity, it would have been impossible to adequately survey large areas and thus provide the necessary information for the compilation of this report. The fact that many of our localities were finally judged to be of low significance level ("3") reflects largely on the nature of many vertebrate fossil localities where all the material was quickly collected with no evident prospect of making further finds in the future. The material collected was, simply stated, "all that was there."

Second, most of the famous, fossiliferous collecting areas known in the San Juan Basin were not included in the SJPU and RPRA. Some that were, namely the Nacimiento Formation exposures in the Kutz Canyon and Torreon Wash, received little or no survey effort on our part because they had already been surveyed by the 1977 Bureau of Land Management survey (Kues et al., 1977) and nominated as paleontological preserves. Therefore, additional detailed examination of them was considered unwarranted.

These previously un- or little surveyed areas were, in large part, found to be essentially devoid of significant fossil material. Thus, as an example, large tracts of the Kirtland Formation badlands in the vicinity of Pinyon Mesa in the SJPU were found to be virtually barren of good vertebrate fossils, although a few highly fragmentary dinosaur materials were observed. These badlands appear to contain sparse, and generally poorly preserved, plant and/or invertebrate remains. The net result was that our team members spent much

time walking potentially fossiliferous outcrops only to find the most fragmentary and generally insignificant material.

Thus, the selectivity of our collecting efforts as well as the simple fact that many sparsely fossiliferous to barren outcrops were surveyed, accounts for the fact that just 191 localities were discovered. We maintain that our survey effort (coupled with the extensive literature review) provides the basis for an adequate inventory of the paleontological resources of the RPRA and SJPU.

Personnel

The principal investigator on this project was Dr. Sidney Ash (Weber State College, Ogden, Utah) and the Field Supervisor was Spencer Lucas (Ph.D. candidate, Yale University). They were assisted in the field by Dr. David Medlyn of Yankton College and Dr. Lee Parker of California Polytechnic University and the following students: Brooks Britt (BYU), Don Elmer (Weber State College), Britt Leatham (Weber State College), Tom Prince (Weber State College), Steve Robison (BYU), Leslie Smith (BYU), Robert Sullivan (Michigan State University) and Sam Webb (BYU).

This report was prepared by Sidney Ash, Spencer Lucas and Don Tidwell with the assistance of Lee Parker who also identified the plants found during the course of the project. Dr. Barry Kues (University of New Mexico) identified the invertebrate fossils and Lucas identified the vertebrate fossils.

SAN JUAN PLANNING UNIT

DESCRIPTION

The San Juan Planning Unit (hereafter "SJPU") consists of approximately 2100 square miles located in northwestern New Mexico (Fig. 1). It includes the cities of Farmington, Bloomfield, and Aztec as well as a major coal strip mine, natural gas and oil fields, and the Navajo Dam and Reservoir. Consequently the SJPU is undergoing intense and rapidly increasing land use of various kinds.

Because of the economic development of the area, virtually all of the SJPU is readily accessible via paved or improved dirt roads. Topographic map coverage of the entire area and surrounding regions is available (Fig. 2), and geologic maps of the SJPU have been published (see Dane and Bachman, 1965 and references cited therein). A simplified geologic map of the SJPU is given in Figure 3.

Sedimentary rocks of Late Cretaceous and Early Tertiary (Paleocene-Eocene) age underlie and are widely exposed in the SJPU (Fig. 3). They include a total thickness of about 7,000 feet of sedimentary rocks (Fig. 4). These rocks represent the last cycles of the Cretaceous epicontinental seaway (Point Lookout Sandstone, Menefee Formation, Cliff House Sandstone, Lewis Shale and Pictured Cliffs Sandstone) that bisected North America and the subsequent changeover to strictly continental sedimentation (Fruitland Formation and Kirtland Shale). This changeover culminated in the formation of an intermontane basin during the early Tertiary (Ojo Alamo Sandstone, Nacimiento Formation and San Jose Formation). We estimate that approximately 24 percent of the SJPU consists of exposures of these strata. The remainder of the area is covered by Quaternary alluvium and terrace gravel

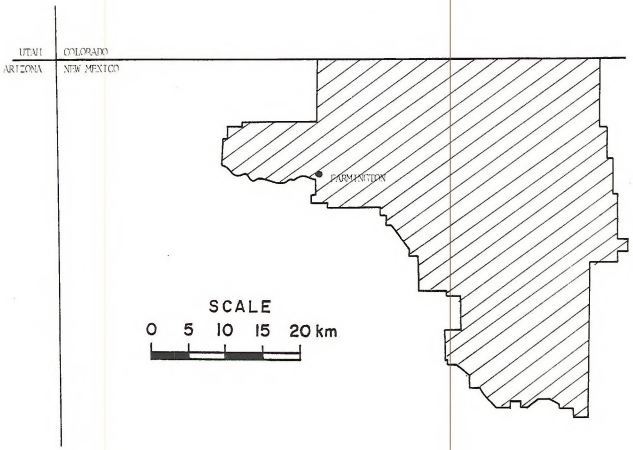


Figure 1. Index map showing the location of the San Juan Planning Unit in northwestern New Mexico.

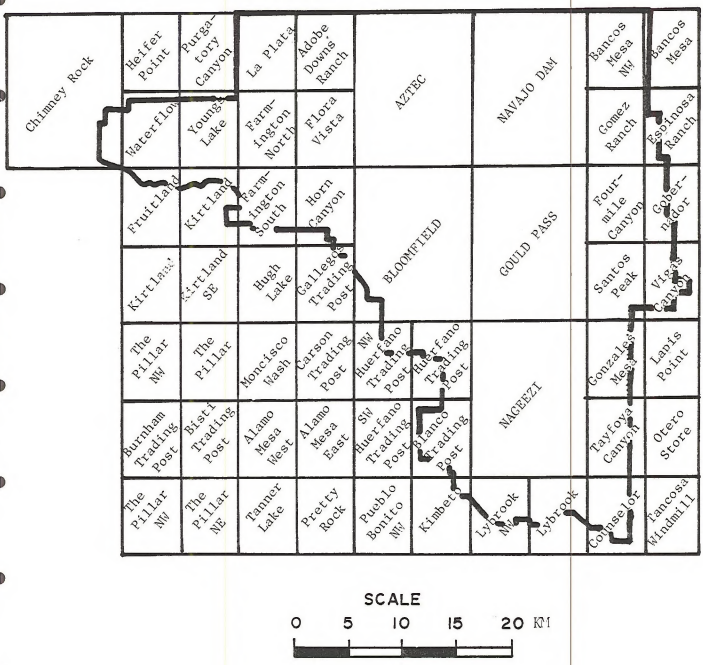


Figure 2. Topographic map coverage of the San Juan Planning Unit.

FIGURE 3.
GEOLOGIC MAP of the SAN JUAN PLANNING UNIT

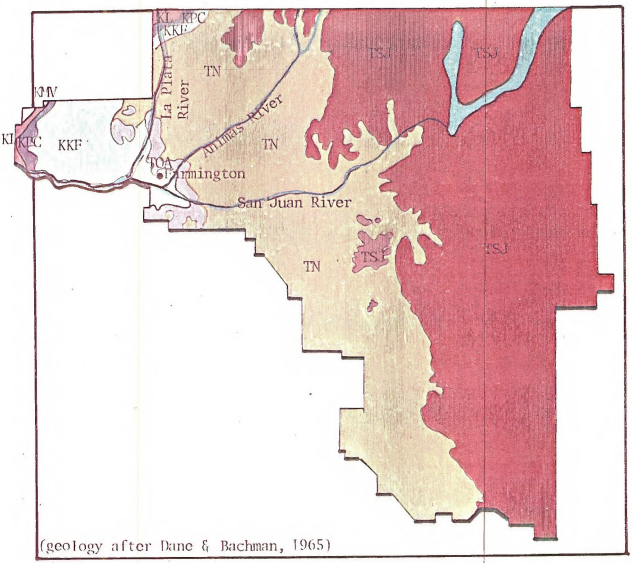


FIGURE 4.
Stratigraphic section showing formations (lithology schematic) that crop out in the San Juan Planning Unit. The Point Lookout Sandstone Menefee Formation and Cliff House Sandstone are often combined into the MesaVerde Group.

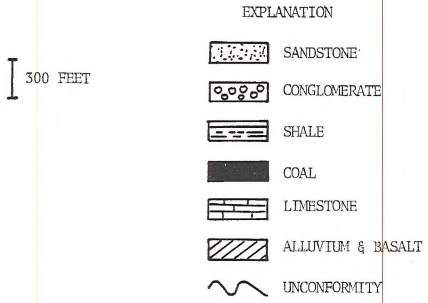


Figure 4.

Lithology	Rock Strat. Units	Age	Fossil Content
	Alluvium	Quaternary	None reported
	San Jose Formation	Early Eocene	Diverse vertebrate faunas of primitive mammals, turtles, crocodiles, fish, lizards, snake, and a bird. Some fresh water gastropods and unionids. Rare fossil leaves and some petrified wood.
	Nacimiento Formation	Early to middle Paleocene	Diverse vertebrate faunas of mammals, etc. Some fresh water invertebrates, wood and leaves.
	Ojo Alamo Sandstone	Earliest Paleocene	Rare fossil mammals. Much petrified wood.
	Kirtland Shale	Late Cretaceous	Dinosaurs, turtles, crocodiles, and other vertebrates. Leaves and wood locally abundant. Some fresh water invertebrates.
	Fruitland Formation	Late Cretaceous	Similar to Kirtland but also some brackish water inverts, and much fossil wood and leaves.
	Pictured Cliffs Sandstone	Late Cretaceous	Marine invertebrates and trace fossils.
	Lewis Shale	Late Cretaceous	Bivalves, ammonites, and other marine invertebrates. One mosasaur.
	Cliff House Sandstone	Late Cretaceous	Marine invertebrates and trace fossils, sharks teeth.
	Menefee Formation	Late Cretaceous	Fossil leaves and wood common. Rare vertebrates (mostly shark teeth and turtle scrap) and invertebrates.
	Point Lookout Sandstone	Late Cretaceous	Marine invertebrates and trace fossils, sharks teeth.

(Table 2). Most of the exposed rocks belong to the San Jose and Nacimiento formations, whereas strata of Cretaceous age are exposed over a comparatively small part of the SJPU (Table 2).

The biota preserved in the Upper Cretaceous formations is extremely diverse and includes marine invertebrates and vertebrates of the Cretaceous seaway, as well as terrestrial vertebrates (dinosaurs and other reptiles, mammals, etc.), nonmarine invertebrates (unionids and gastropods), and plants that lived on the deltas and coastal plains bordering the seaway. The Lower Tertiary strata in the SJPU contain the remains of terrestrial vertebrates (mammals, turtles, crocodiles, etc.), nonmarine invertebrates, and plants that lived on the floodplains which covered this area after the seaway disappeared.

PREVIOUS PALEONTOLOGICAL STUDIES

In the past the Upper Cretaceous and Lower Tertiary rocks of the SJPU, with the exception of the Nacimiento Formation along the western rim of Kutz Canyon, have not been studied very intensively by paleontologists. This is due to two factors:

(1) Until the advent of extensive drilling for natural gas and oil, a large part of the SJPU, particularly the extensive exposures of the San Jose Formation along its eastern edge, was virtually inaccessible to travel except by horse or by foot. This discouraged collecting efforts in parts of the SJPU.

(2) Extremely fossiliferous outcrops of all the stratigraphic units exposed in the SJPU are known further south in the San Juan Basin (Kues et al., 1977). With the exception of the Paleocene mammal sites in Kutz Canyon, no major collecting field for fossil vertebrates, invertebrates, or plants has ever been discovered in the SJPU.

Table 2

Estimated outcrop areas of the formations exposed in the San Juan Planning Unit.

Formation	Estimated Outcrop Area (square miles)	Percentage of SJPU
Quaternary alluvium	527	25
San Jose Formation		
poor exposures	1010	49
good exposures	172	8
Nacimiento Formation	294	14
Ojo Alamo Sandstone	25	1
Kirtland Shale	45	2
Fruitland Formation	10	<1
Picture Cliffs Sandstone	3	<1
Lewis Shale	4	<1
Mesa Verde Group	10	<1
Totals	2100	100

A review of all previous paleontological studies in the SJPU was presented by Kues et al. (1977) as part of their paleontological survey for the Bureau of Land Management. Table 3 is a brief summary of these studies including the study of Kues et al. (1977).

Faunal and floral lists for the stratigraphic units in the SJPU were given by Kues et al. (1977) and reprinted with minor corrections by the U.S. Bureau of Land Management (1978). Not all of the taxa in these lists have been found in the SJPU, but there is no reason not to expect most of these taxa to be there. Indeed, previous field studies (Table 3), as well as our own, have confirmed the presence of many of these taxa within the SJPU. However, to determine which of the taxa in the lists given by Kues et al. (1977), especially among the Cretaceous marine invertebrates and dinosaurs, are present in the SJPU is beyond the scope of this study. Thus, for the present it will be assumed that all taxa listed by Kues et al. (1977) for the stratigraphic units in the SJPU are present in this area.

PRESENT STUDY

In the course of our fieldwork, the entire SJPU was reconnoitered, but only selected areas including the critical areas (Fig. 5) were surveyed (Fig. 6). These surveyed areas and the rationale justifying their survey are as follows:

(1) Nacimiento Formation outcrops in the Bohannon Canyon critical area produced a small collection of fossil mammals for the American Museum Expeditions in 1913 and 1916 (Sinclair and Granger, 1914; Granger, 1917), and a small part of this area was surveyed by the University of New Mexico team (Kues et al., 1977). However, no prolonged intense survey has ever

Table 3

Summary of the history of paleontological work in the San Juan Planning Unit

Formation	Dates, worker and nature of work	Publications
San Jose Fm.	1977, Kues et al., survey of area south of Gobernador.	Kues et al., 1977.
Nacimiento Fm.	1913, 1916, Amer. Mus. Nat. Hist. expeditions, Kutz Canyon and along Animas River.	Sinclair and Granger, 1914; Granger, 1917.
	1948, 1950, 1956, Univ. Kansas, Kutz Canyon.	Wilson, 1949, 1950, 1951, 1956a, 1956b, 1956c; Wilson and Szalay, 1972; Kay and Cartmill, 1974, 1977.
	1974-1979, Univ. Ariz., and 1977, Kues, et al, Kutz Canyon	Lindsay, et al., 1978; Kues, et al., 1977.
Ojo Alamo Ss., Kirtland Shale, Fruitland Fm., Pictured Cliffs Ss., Lewis Shale, and Mesa Verde Group	1870's to present, various groups. Mostly geologic mapping and stratigraphic studies, some collecting.	Holmes, 1877; Bauer, 1916; Lee, 1917; Reeside, 1924; Baltz et al., 1966; Fassett and Hinds, 1971 and others cited by these workers.

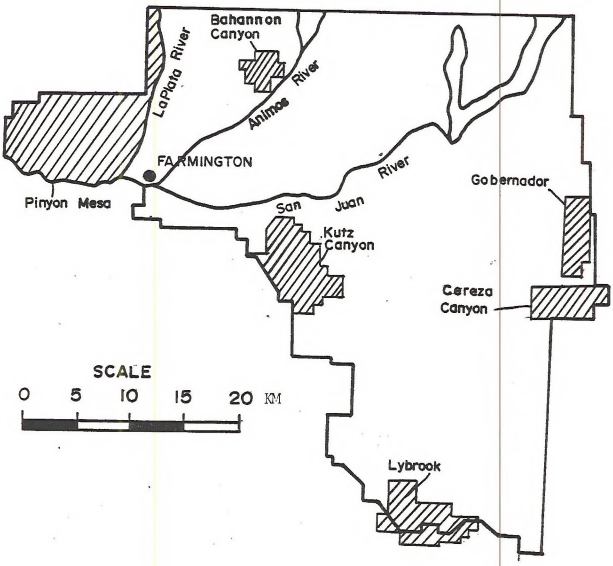


Figure 5. Critical areas in the San Juan Planning Unit.

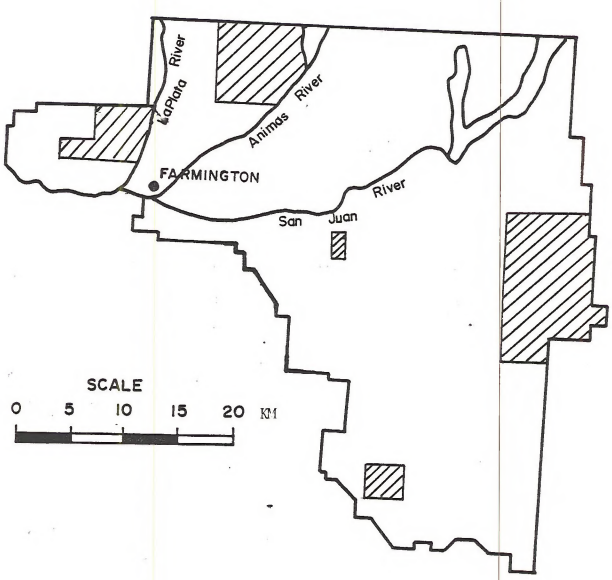


Figure 6. - Principal areas (hatched) in the San Juan Planning Unit surveyed by our team during the fieldwork phase of our project.

been conducted in this critical area and we felt that some survey was necessary in order to determine how fossiliferous these exposures are.

(2) Outcrops of the Lewis Shale, Picture Cliffs Sandstone, Fruitland Formation, Kirtland Shale, and Ojo Alamo Sandstone in the Pinyon Mesa critical area are experiencing intense land use due to the boom town expansion of Farmington, the Western Coal strip mine, and an abundance of new oil and gas wells, power lines, roads and housing developments in the area. This area includes the type section of the Pictured Cliffs Sandstone (Holmes, 1877, Reeside, 1924) and immediately adjoins the type areas of the Fruitland Formation and Kirtland Shale (Bauer, 1916, Reeside, 1924). Because of the intense land use in the area containing these stratigraphically important type localities, we felt survey of parts of this area was imperative.

(3) The Kutz Canyon critical area consists of extensive exposures of the Nacimiento Formation, parts of which have been intensively surveyed by parties from the American Museum (Sinclair and Granger, 1914; Granger, 1917), University of Kansas (Wilson, 1949, 1950, 1951, 1956a, 1956b, 1956c; Wilson and Szalay, 1972), University of Arizona (Lindsay et al., 1978), and University of New Mexico (Kues et al., 1977). We devoted minimal time to survey of the Kutz Canyon area because we felt that these previous surveys had already established this area as an important (indeed world-famous) locality for the collection of Middle Paleocene (Torrejonian) mammals. Moreover, our survey time spent in Kutz Canyon was spent in a part of the Canyon unexplored by previous surveys.

(4) Exposures of the Regina Member of the San Jose Formation in the Cereza Canyon critical area were first partially surveyed by the University of New Mexico team (Kues et al., 1977) and found to be sparsely fossiliferous.

Nevertheless, the great majority of this area was totally unexplored, and thus, it was necessary to devote a relatively large amount of time to its survey.

(5) The Lybrook critical area consists of a large area of Nacimiento Formation badlands with lesser amounts of San Jose Formation outcrops. We devoted a minor amount of time to this area, attempting to survey some of those outcrops not examined by the University of New Mexico team in 1977 (Kues et al., 1977).

Our fieldwork discovered 88 localities, broken down according to location and level of significance in Table 4. As shown in the table, only 6 of the localities are definitely worth recollecting and/or preserving. The majority of the localities have a low level of significance. The results of the fieldwork combined with the literature search merge to produce what is considered to be a relatively complete inventory of the paleontological resources in the SJPU.

CURRENT LAND USE

One of the objectives of our fieldwork was to observe and document land use activities in the SJPU that are at present adversely affecting paleontological resources or are likely to adversely affect paleontological resources in the future. The major types of land use activities that fit this description are:

(1) Grazing and the concomitant activities of fence building and stock tank construction.

(2) Road building, the most severe land use being paved highway construction, the least severe being unimproved dirt road construction.

(3) Off-road vehicles.

(4) Coal strip mining and other forms of surface mining and small scale excavation (e.g., gravel pits).

(5) Power line and gas pipeline corridors.

(6) Drill pads and sites for water, gas, and oil drilling.

Table 4

Summary of the significance level of localities found in the San Juan Planning Unit during the present survey.

Definition of the levels are as follows:

Level 1 = Highest significance (definitely worth recollecting and/or preserving).

Level 2 = Moderately significant (possibly worth recollecting, especially after further weathering).

Level 3 = Insignificant (not worth recollecting).

Significance Level	Number of Localities
1	6
2	29
3	53

(7) Urban expansion, including housing developments and the construction of relatively isolated one family houses.

(8) Dams such as the Navajo Dam and the resulting inundation of large outcrop areas behind the dam.

(9) Trash dumps and landfill sites.

Some of these land use activities that are adversely affecting paleontological resources within the SJPU are illustrated in Figures 7 and 8. Table 5 presents an analysis of the significance of each of these land use activities in terms of their adverse effects on paleontological resources in general. Table 6 is our evaluation of the present significance of each of these land use activities in the critical areas in Figure 5.

MITIGATION AND MANAGEMENT SUGGESTIONS

Philosophy

An extensive discussion of the nature of paleontological resources, their importance, methods of fossil collection and a framework of mitigation procedures (establishment of paleontological preserves, salvage, etc.) was presented by Kues et al. (1977). It would be superfluous to repeat that presentation here especially since we generally agree with the discussion in Kues et al. (1977). Instead our approach is a site-specific discussion of mitigation and management suggestions. In other words, we will identify scientifically and/or aesthetically significant fossil sites and areas and present specific management recommendations for each.

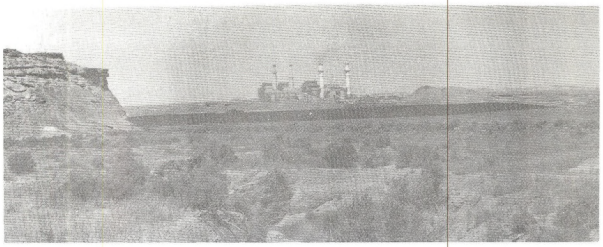
However, we first would like to digress and briefly discuss one point regarding the philosophy of management of paleontological resources that was not stated clearly enough nor sufficiently emphasized by Kues et al. (1977). This concerns the scientific study of fossils. The value of

Figure 7. Land use activities in or near the San Juan Planning Unit, I.

A. The San Juan Generating Station northwest of Farmington. Coal for the plant is obtained from the Fruitland Formation.

B. Urban development. Farmington. Originally the town developed on the flood plain of the San Juan River but recently homes and commercial structures have been built on adjacent exposures of the Kirtland Shale and Fruitland Formation.

C. Sanitary landfill for Farmington. The pits are dug into the Kirtland Shale.



A

B

C

FIGURE 7. Land use activities, SJPU, I

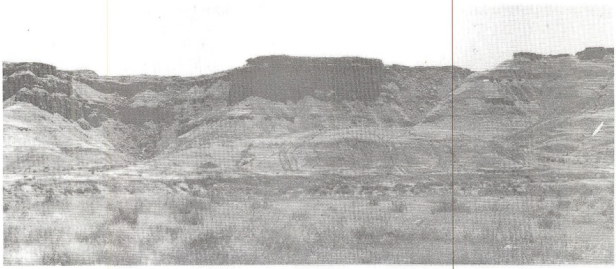
Figure 8. Land use activities in or near the San Juan Planning Unit, II.

A. Four Corners Generating Station with the Hogback in the background. Coal for this plant is obtained from the type Fruitland Formation.

B. Off-road vehicle trails cut on the type Kirtland Shale, west of Farmington.

C. New Mexico State highway 44 road cut through the Nacimiento Formation near Lybrook.

A



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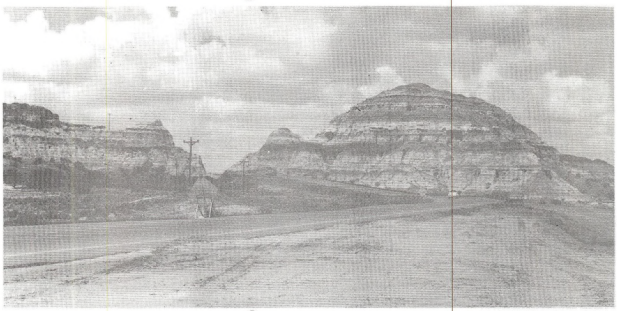

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FIGURE 8. Land use activities, SJPU II

Table 5

Rating of land use activities in the San Juan Planning Unit

Land Use Activity	General impact on Paleo. Resources	Comments
1) Grazing and related construction	low	Only impacts when stock tanks or roads built through outcrops containing fossils.
2) Road building	moderate	High if built through outcrops containing fossils.
3) Off road vehicles	moderate	Often crosses outcrops so has great potential to be of high impact.
4) Mining	moderate-high	Generally built on alluvium covered surfaces but high if in rocks containing fossils.
5) Powerline and pipeline corridors.	moderate	Similar to road building.
6) Drill pads	moderate	When built on outcrops very destructive of relatively large area surrounding drill hole.
7) Urban expansion	high	Results in increases in almost all other forms of land use that have an adverse affect on fossils.
8) Dams and reservoirs	low	High if fossiliferous outcrops are inundated.
9) Dumps and landfills	low	Usually constructed in or on alluvium but if built on rocks containing fossils the impact will be high.

Table 6

Evaluation of land use activities in critical areas of the San Juan Planning Unit.

x = land use activity determined to be presently adversely affecting paleontological resources.

- = not adversely affecting paleontological resources at present.

Land Use Activity	Pinyon Mesa	Bohannon Canyon	Kutz Canyon	Cereza Canyon	Lybrook	Gobernador
1) grazing	-	-	-	x	-	x
2) road building	x	x	-	x	x	x
3) off road driving	x	-	-	-	-	-
4) mining	x	-	-	-	-	-
5) powerlines and pipelines	x	x	x	x	x	x
6) drill pads	-	x	x	x	x	x
7) urban expansion	x	x	-	-	-	-
8) dams and reservoirs	-	-	-	-	-	-
9) dumps and landfills	x	x	-	-	-	-

fossils is twofold: they are either of scientific importance because of the information about the evolution of past organisms and communities they contain (see discussion by Kues et al., 1977) and/or of aesthetic importance because of their value in museum and park displays for the layman. Generally, only a small percentage of all fossils found are of aesthetic importance because very few well-preserved and relatively complete specimens are found and are suitable for display. Thus the overwhelming majority of all fossils are solely of scientific importance (note that the economic exploitation of paleontological information in petroleum exploration, etc. is merely an outgrowth of the scientific study of fossils) and this fact should be foremost in the formulation of management policies pertaining to paleontological resources. More directly, the proper management of paleontological resources should have as its major goal the facilitation of scientific study of those resources by qualified paleontologists. We recommend that any activity or policy contrary to this goal should be avoided by the Bureau of Land Management. For example any activity which draws attention to important localities can result in the destruction of valuable scientific information. Only by encouraging and promoting scientific research on federal lands will the Bureau of Land Management insure the proper utilization of the paleontological resources of these lands.

Areas Requiring Mitigation

Our survey has identified three areas in the SJPU that we feel require mitigation (Fig. 9):

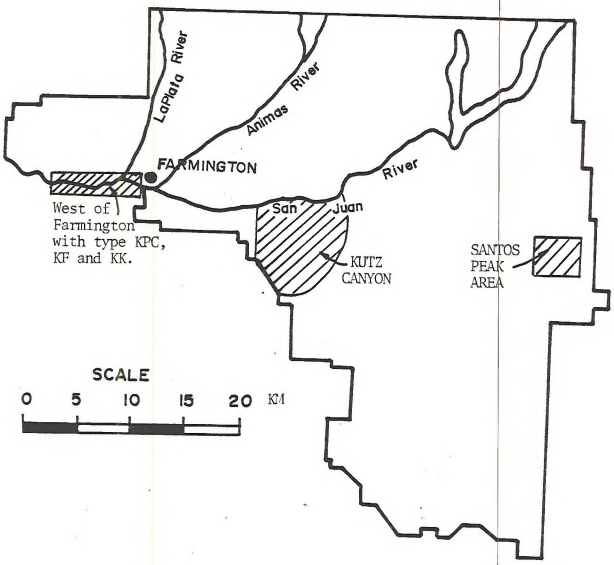


Figure. 9 - Areas in the San Juan Planning Unit (hatched) judged by us to be of sufficient paleontological significance to merit mitigation.

(1) Santos Peak area. Our crew discovered the first known plant megafossil localities in the San Jose Formation in beds of the Regina Member near Santos Peak. These localities contain leaves, fruits and flowers and give the first glimpse of the flora of the San Juan Basin during early Eocene time (Fig. 10). Because of this, and the abundance and excellent preservation of the flora, these localities are of great scientific importance. A preliminary list of plant fossils found by us in the San Jose Formation in the Santos Peak area follows:

Ferns
- Acrostichum hesperium
- Danaea coloradensis

Gymnosperms
- Taxodium olriki

Angiosperms
- Araliaephyllum sp.
- Carpites sp.
- Cinnamonium cf. hesperium
- Engenia americana
- Eucalyptus(?) americanus
- Leguminosites sp.
- Lindera obtusata
- Paleonelumbo macroloba
- cf. Persea coriacea
- Pterocarya-like catkin
- Pterocarya-like fruits
- Salix
- Sapindus dentoni
- grass-like leaf fragments

In addition, several vertebrate localities were discovered in this virtually unexplored area of the San Jose Formation. An example of one of the fossils collected from this area is shown in Figure 11A. At least one of these localities should be screenwashed for small vertebrate remains.

Figure 10. Plant fossils from the Lower Eocene San Jose Formation near Santos Peak, San Juan Planning Unit. The scale in each photograph is in millimeters.

A. Leguminosites sp. fruit. Fruits similar to this fossil are common throughout the Tertiary. No. B63-6.

B, E. Paleonelumbo macroloba. B. Fragment of a large peltate waterlily leaf. No. B68-36. E. Central part of a leaf showing the divergence of 18 primary veins and segments. No. B68-31. When these leaves are complete, they are up to 45 cm in diameter and are relatively common in Eocene floras of western North America.

C. Taxodium olriki. Single leaf of a baldcypress-like tree. Remains of this plant are rare in the San Jose and other Eocene floras. No. B63-10.

D. Acrostichum hesperium. Portion of a large fern frond. Complete fronds were probably up to 1 meter in length. No. B68-1.

F. Eucalyptus(?) americanus. Blade of a leaf. This is a common fossil in several western North American Eocene floras. There are differing opinions about its true relation to the genus Eucalyptus. No. B63-13.

G. Sapindus dentoni. Blade of a leaf. This species has been collected occasionally in other Eocene floras but does not appear to be common. No. B63-7.

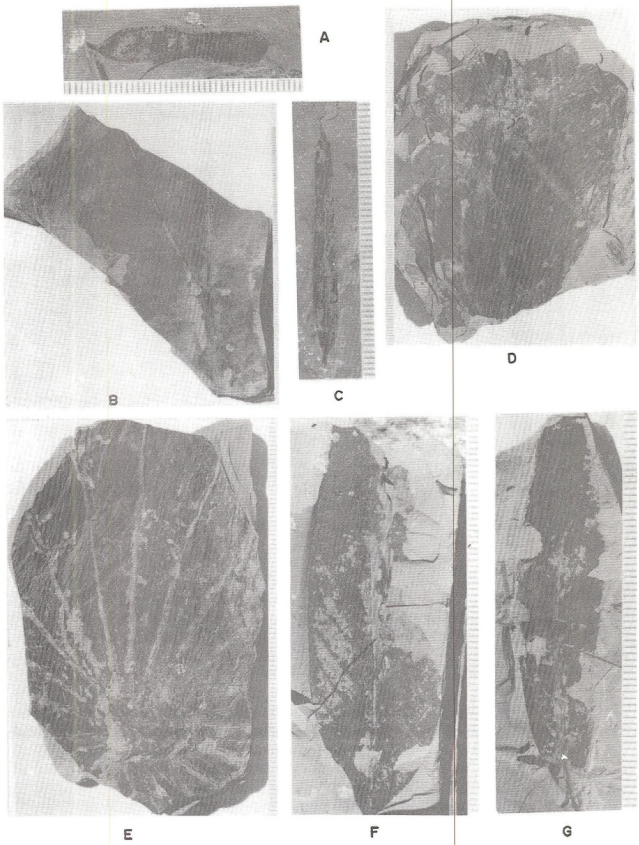


FIGURE 10. Lower Eocene Plant Fossils, SJPU

Figure 11. Mammal fossils from the Early Tertiary rocks in the San Juan Planning Unit. The scale is in millimeters in each photograph.

A. Esthonyx bisulcatus. Occlusal view of left maxillary fragment. No. B61-1. Regina Member of the San Jose Formation near Santos Peak.

B-D. Tetraclaenodon puercensis. Lower left mandible. B, occlusal view. C and D, lateral views. No. B85-2. Nacimiento Formation in Kutz Canyon.

E-G. Periptychus carinidens. Lower left mandible. E, occlusal view. F, and G. lateral views. No. B85-1. Nacimiento Formation in Kutz Canyon.

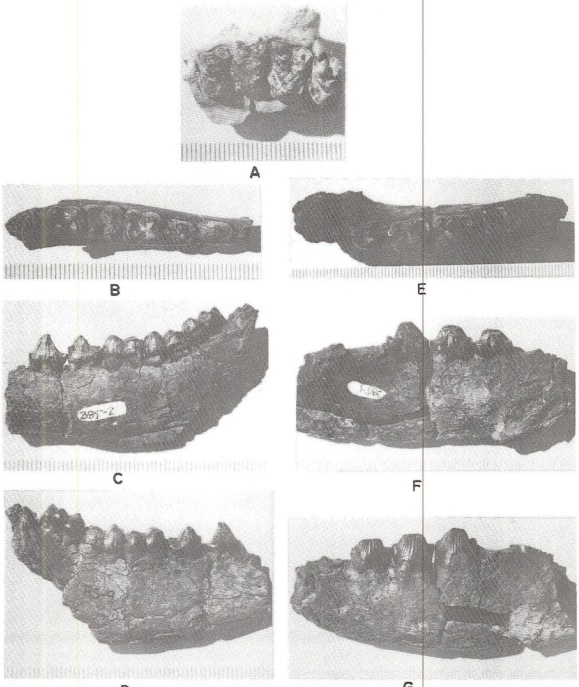


FIGURE II. Mammal Fossils, SJPU

Examples of the vertebrates found in the San Jose include:

Turtle scrap
Crocodile teeth
Hyrachotherium sp.
Esthonyx bisulcatus
Hyopsodus miticulus
Coryphodon sp.

Our specific management suggestion for this area is the salvage and scientific study of the plant and small vertebrate localities. A two week collecting project involving the quarrying of the shales containing the plants would be sufficient to salvage this locality. The collection and scientific study of these plants could constitute a master's thesis project for a paleobotany student.

Depending on its fossil content, the salvage of the small vertebrate locality could involve more time than the fossil plants. To determine this the preliminary removal of 200 to 500 pounds of matrix as a test sample for screenwashing (McKenna, 1962) should be undertaken. If the yield from this sample is 10 to 20 or more identifiable mammal teeth and jaws, then a more extensive screenwashing operation should be initiated. This would require the removal of many tons of sediment and its screenwashing at the nearest usable source of running water (San Juan River). The operation could take several months and would need to be supervised by a vertebrate paleontologist with experience in screenwashing.

The remaining exposures of the San Jose Formation in the Cereza Canyon critical area were found to be sparsely fossiliferous, and we recommend their removal from their present status as a paleontologically critical area. If a "critical area" is to be retained in this part of the SJPU, we recommend its restriction to the area immediately around Santos Peak.

(2) Kutz Canyon Area. The exposures of the Nacimiento Formation that contain numerous Paleocene mammal localities in Kutz Canyon were recommended by Kues et al. (1977; p. 187) to be a "Paleontological Preserve" and we concur with their recommendation. Although we did not spend much time surveying in Kutz Canyon, the reports of earlier workers (see previous discussion) and the experience of the University of New Mexico survey team (Kues et al., 1977) sufficiently documented the importance and continuing productivity of the fossil-bearing beds in Kutz Canyon. Figures 11B-11G illustrate some of the mammal fossils we found in this area.

Even if it is eventually designated a paleontological preserve, we believe that the Kutz Canyon area should be subjected to an intense survey and salvage effort as soon as possible. Such a survey would require a three to four month effort by a ten man crew that would begin with an intense survey of all outcrops in the canyon. The next step would be salvage by quarrying and screenwashing of all localities discovered that merit such collecting. Additional quarrying and screenwashing might be necessary at a later date for selected highly fossiliferous sites. This whole operation should be supervised by a vertebrate paleontologist, preferably one whose expertise centered on Early Tertiary mammals.

(3) Area west of Farmington. The type sections or areas of the Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale are west of Farmington along the San Juan River either within or adjacent to the SJPU (Fig. 12). Type sections have a stratigraphic, and hence paleontologic, importance that should not be underestimated. They are as important as type specimens of biological taxa in that they are the name bearers of nationally and internationally recognized rock-stratigraphic units. Their selection and designation is controlled by the geologic names committee of the United States Geological Survey (Wilmarth, 1938). Type sections (areas) should not be destroyed or severely altered by

Figure 12. Type areas of certain Upper Cretaceous units in or near the San Juan Planning Unit.

A,B. Kirtland Shale in the type area south of the San Juan River near Kirtland and Fruitland.

C. Pictured Cliffs Sandstone in the type area just north of the San Juan River between Farmington and Shiprock. U.S. Highway 550 in the foreground.

A

B

C

FIGURE 12. Upper Cretaceous Rocks, SJPU

land use of any kind. We recommend that the Bureau of Land Management take steps to insure the protection of the type sections (areas) of these units. The problem of protection of the type area of the Fruitland Formation is particularly poignant since the Navajo Coal Mine is strip mining it away. If measures to save part of the Fruitland type area cannot be implemented, then we suggest that the United States Geological Survey names committee be contacted and the selection of a new type section be suggested.

A summary of our recommendation for these areas is contained in Table 7.

Outside of the three areas discussed above, our survey did not reveal any other areas in the SJPU that we feel merit mitigation. Although it is always possible that important localities will be discovered outside of the three areas suggested for mitigation, our survey reveals that at present these are the only areas in the SJPU that available data indicate are deserving of mitigation.

The Bohannon Canyon and the Lybrook critical areas have produced some important fossils, but they were not found to be very fossiliferous by our crews, certainly not as fossiliferous as equivalent strata further south in Torreon Wash or in Kutz Canyon. We recommend that they be dropped from the status of paleontologically critical areas. In addition, large portions of the SJPU, especially the massive cliffs and ledges of San Jose Formation sandstones around Navajo Reservoir and in Canon Largo, seem to have little potential for producing important fossils.

Table 7
Summary of Mitigation and Management Suggestions
for Paleontologically Significant Areas in the San Juan Planning Unit.

Area	Formation	Nature of Occurrences	Mitigation and Management Suggestions
Santos Peak	San Jose Formation	Leaf locality	Quarrying (= 2 weeks) by a qualified paleobotanist
		Small vertebrate locality	Screenwashing (= 3-4 months) by a team supervised by a vertebrate paleontologist
Kutz Canyon	Nacimiento Formation	Abundant fossil vertebrate localities (especially mammals)	Designate a "Paleontological Preserve," collected initially (3-4 months) by a ten man crew supervised by a vertebrate paleontologist.
West of Farmington	Pictured Cliffs, Kirtland, Fruitland Formations	Type sections of rock-stratigraphic units	Prevent destruction by industrial and other activities.

The extensive badlands of the Nacimiento Formation exposed in the Bohannon Canyon "Critical Area" were the object of a significant portion of our survey time (about 30 man days) but failed to produce fossil remains of sufficient quality and quantity to convince us that the area should retain the status of a "Critical Area." In the past, the Bohannon Canyon area has produced some fossil material, mostly of middle Paleocene (Torrejonian) age fossil mammals, including the types of several genera and/or species of Paleocene mammals. However, none of this material, including the type specimens, was ever more than an uncommon jaw (or jaw fragment), isolated teeth or bones. Furthermore, as shown below, all of the taxa presently known from the Bohannon area have been duplicated by more complete and better preserved material from elsewhere in the San Juan Basin.

Collecting in the Bohannon Canyon area began in 1879 when David Baldwin sent O. C. Marsh of Yale University a variety of isolated teeth and bone fragments collected in various areas near the Animas and La Plata Rivers (Simons, 1963). He also sent a fragmentary lower jaw that Marsh (1894) named "Eohyus robustus." This specimen (Yale Peabody Museum 11887) was recently examined by one of us (SGL) and is an essentially edentulous right ramus from the symphysis to the partial M^3 plus some associated tooth and left ramus fragments. This type specimen is hardly "good" or "complete" material, and it is a misfortune that Marsh chose this material as the basis of a new species. Sinclair (1914) has correctly pointed out that this specimen is referrable to Periptychus, and thus "Eohyus robustus" is a subjective synonym of Periptychus, probably Periptychus carinidens Cope. Better specimens of Periptychus, including the skull of P. coarctatus and a partial skeleton of "Rhabdodon" (see Matthew, 1937, figs. 21-23, 26) are known from localities elsewhere in the San Juan Basin.

In the early 1880's Baldwin returned to the Bohannon Canyon area in the employ of E. D. Cope. He obtained more fossil material than he had earlier, but it was nothing more than a rare jaw or jaw fragment, isolated teeth or bones. Nevertheless, Cope based a couple of new genera and species on some of these scrapy specimens. According to Granger (1917) specimens that can with some degree of certainty be attributed to Baldwin from the Bohannon area are:

a. "Various teeth" and a humerus of mammals, generically indeterminate, that came from localities which Baldwin's field labels describe as "north side San Juan on Animas" and "west side Animas."

b. The type specimen (AMNH 3029) of "Neoplagiaulax molestus" Cope, 1886, a single lower premolar "with skeletal fragments." This specimen was considered so inadequate as to be indeterminate. Therefore, Granger and Simpson (1928, 1930) designated it a neotype for Eucosmodon (= Neoplagiaulax) molestus, a left lower jaw with the incisor and P^4 (AMNH 17063).

c. The type of Pantolambda cavirictus Cope was, according to Baldwin's packing label, from the "Ute Reserve near Durango, N.M." It is conceivable that it also came from the Bohannon area or the immediate vicinity. The fossil is a nearly complete lower jaw (AMNH 3961). A skull of Pantolambda cavirictus, additional lower jaw material (including a poorly preserved juvenile dentition) and various postcrania, collected by Wortman from the Torreon Wash area, were described and illustrated by Osborn and Earle (1895) and Matthew (1937). Thus, although the type of Pantolambda cavirictus is a relatively good specimen, it is hardly the best available material of that species.

According to Granger (1917, p. 823), other material collected by Baldwin in the northern part of the San Juan Basin was mostly listed by Baldwin as coming from the "Rio San Juan" or "Mouth of Canon Largo." This material most likely came from Kutz Canyon and adjacent canyons and not from the Bohannon Canyon area.

Granger collected from the Bohannon Canyon area in the earlier years of this century and reported several mammalian taxa (Granger, 1917, p. 825):

Periptychus rhabdadon
Mioclaenus turgidus
Tetraclaenodon sp.
Misodectes sp.
Pentacadon sp.
Tricentes sp.
Didymictis haydenianus
Claenodon sp.
Deltatherium sp.
Pantolambda cavirictus

These fossils were found in a variety of canyons near the Animas and none was of such exceptional quality that it was figured or formed the basis for a type (including paratype, topotype, neotype) specimen. It did, however, serve to confirm the Torrejonian age of the strata of the Nacimiento Formation in this region (Granger, 1917).

It is significant that, although fossils were known from the Bohannon area, essentially nobody returned to collect after Granger until the Bureau of Land Management survey of 1977 (Kues et al., 1977). We believe this lack of interest reflects two circumstances:

1. Although mammal fossils were known from the Bohannon area, they were, as demonstrated above, generally fragmentary or incomplete specimens, and, as is evident from Granger's (1917) discussion of the area, it was not particularly fossiliferous.

2. Much richer collecting fields for Torrejonian mammals, particularly on the east and west flanks of Torreon Wash (Sinclair and Granger, 1914) and the western rim of Kutz Canyon (Wilson, various papers) have been known for about as long as the Bohannon Canyon area.

The 1977 Bureau of Land Management survey intensively surveyed 1-1/2 sections discovering nine localities in Nacimiento Formation exposures in the Bohannon Canyon Area (Kues et al., 1977, Table 6). On this basis they made the following assessment (Kues et al., 1977, p. 199).

> A rich and diverse assemblage of Paleocene mammal jaw fragments and teeth was collected from these sites (i.e., their localities 1112 and 1113 in Bohannon Canyon), including one probable new genus and two new species. Neighboring localities contained turtle bone fragments. Although isolated, the presence of important mammal remains in Bohanan [sic] Canyon is now documented, and a substantial effort in surveying, surface collecting, and possible exploratory screening in unprospected parts of this and adjacent canyons is warranted. Prospecting in Bohanan [sic], Tucker and Kiffen Canyons would require a month or more of time by a crew of 4 (100 + days).

Because of this, it was considered necessary to devote as much time as possible to the survey of Bohannon and adjacent canyons along the west side of the Animas River, in spite of the fact, that the time constraints of the contract survey would not allow the team to devote the "100+ days" to this area recommended by Kues et al. (1977).

Our survey of this area revealed the presence of scattered, small localities throughout the region. We discovered 43 localities in the Bohannon Canyon "Critical Area." No locality in this area produced more than a couple of jaw fragments, and most consisted of an isolated tooth plus bone scrap and/or a range of turtle, crocodile and gar bone fragments and petrified wood. Our reexamination of the Kues et al. (1977) localities 1112 and 1113 revealed them to be barren, no significant observable fossils having weathered out since 1977. The possibility that screenwashing could be profitably carried out at one or both of these localities cannot be discounted. But such an operation was beyond the scope of our survey. One of us (SGL) has had extensive collecting experience in the highly fossiliferous Torrejonian fossil collecting field in Torreon Wash and Kutz Canyon. His experience in Bohannon Canyon and adjacent canyons, while prospecting for this survey, supports the general impression voiced by all our fieldworkers. That is the outcrops of the Nacimiento Formation in Bohannon Canyon are sparsely fossiliferous. They only yield an occasional mammal fossil. These remains are generally isolated teeth and jaw fragments of taxa already known from more complete material from other parts of the San Juan Basin.

From the above discussion the following conclusions are drawn:

1. In the past the Bohannon Canyon "Critical Area" has produced some remains of Torrejonian mammals but these are generally isolated teeth and jaws of taxa already known from better specimens from other localities in the San Juan Basin.

2. Because our survey failed to reveal any well-preserved, abundant or otherwise exceptional fossils (vertebrates, or otherwise) in the Bohannon Canyon "Critical Area," it is recommended that its "Critical" status be dropped.

RIO PUERCO RESOURCE AREA

DESCRIPTION

The Rio Puerco Resource Area (hereafter "RPRA") consists of approximately 1100 square miles located in northwestern New Mexico (Fig. 13). The only settlement in the RPRA that approaches city size is Cuba, although a number of smaller settlements (e.g., Lindrith, Regina, San Ysidro) are present. As in the SJPU, a large variety of land use activities are present in the RPRA including gas, water and oil drilling, road building and grazing. In contrast with the SJPU, urban expansion and coal strip mining are not as yet major land use activities in the RPRA. Indeed, large tracts of the RPRA are still relatively inaccessible because they are densely forested or are extensively eroded into badlands and deep canyons.

Topographic coverage of the entire area and surrounding regions is available as shown in Figure 14. In spite of its inaccessibility excellent geologic maps of the RPRA have been published (see Dane and Bachman, 1965 and references cited therein) and in general the geology of this area is well understood. The same sequence of Upper Cretaceous and Lower Tertiary rocks present in the SJPU underlies and crops out throughout most of the RPRA (Figs. 15 and 16). In addition, small exposures of younger Tertiary strata (the Late Eocene portion of the Galisteo Formation and the Miocene Zia Sand) occur along the southern edge of the RPRA. A thick sequence of Mesozoic rocks (Chinle Formation, San Rafael Group, Morrison Formation, Dakota Sandstone, Mancos Shale, Gallup Sandstone, Crevasse Canyon Formation) also crops out in the RPRA. The most extensive outcrop area is occupied by the deltaic deposits of coal, sandstone, and mudstone of the Menefee Formation (Table 8). Broad exposures of the Mancos Shale, Nacimiento and San Jose formations are present also in parts of the RPRA.

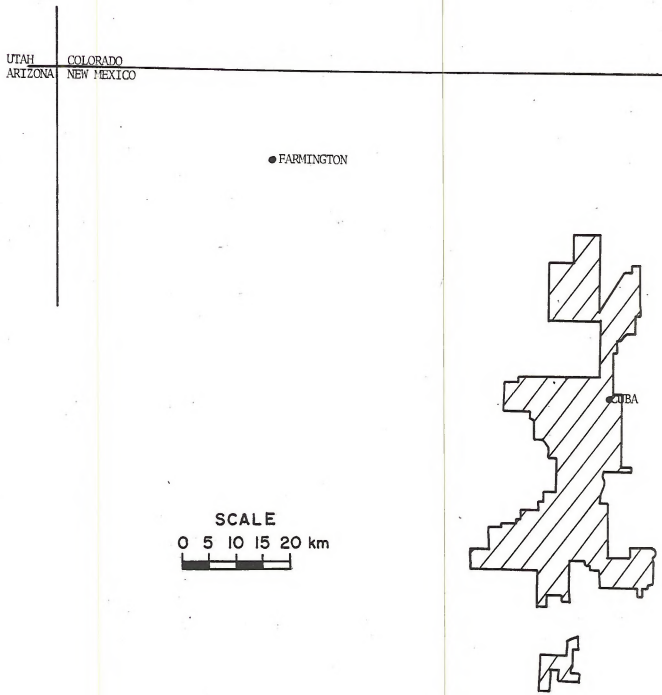


Figure 13. Index map showing the location of the Rio Puerco Resource Area in northwestern New Mexico.

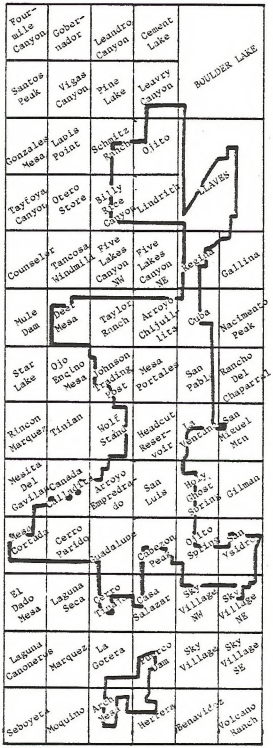
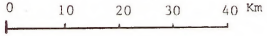


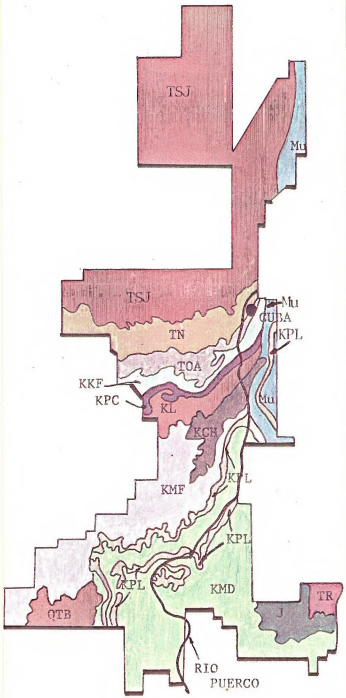
Figure 14. Topographic map coverage of the Rio Puerco Resource Area in northwestern New Mexico.

FIGURE 15.
GEOLOGIC MAP
of
THE RPRA



LEGEND

	QTB	QUATERNARY ALLUVIUM AND TERTIARY BASALTS
	TSJ	SAN JOSE FORMATION
	TN	NACIMIENTO FORMATION
	TOA	OJO ALAMO SANDSTONE
	KKF	KIRTLAND SHALE AND FRUITLAND FORMATION
	KPC	PICTURED CLIFFS SANDSTONE
	KL	LEWIS SHALE
	KCH	CLIFF HOUSE SANDSTONE
	KME	MENEFEE FORMATION
	KPL	POINT LOOKOUT SANDSTONE
	KMD	MANCOS SHALE, DAKOTA SANDSTONE, GALLUP SANDSTONE UNDIFFERENTIATED
	J	MORRISON FORMATION AND SAN RAFAEL GROUP
	TR	CHINLE FORMATION
	MU	MESOZOIC AGE ROCKS UNDIFFERENTIATED


TSJ
Mu
TSJ
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CUBA
KPL
TN
TOA
KKF
KPC
KL
Mu
KCH
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KMF
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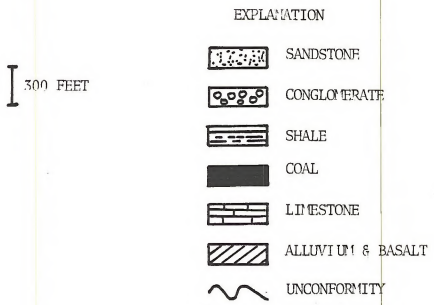
KPL
KMD
TR
QTB
J
RIO
PUERCO
KMD
J

FIGURE 16. Stratigraphic section showing formations (lithology schematic) that crop out in the Rio Puerco Resource Area. The Summerville Formation, Todilto Limestone, and Entrada Sandstone are combined to form the San Rafael Group.



Lithology	Rock-Strat. Units	Age	Fossils
	Alluvium	Quaternary	None reported
	Zia Sand	Miocene	Fossil mammals, principally rodents.
	Upper part of Galisteo Formation	Late Eocene	Some petrified wood and fossil mammals, mostly titanotheres.

Lithology	Rock - Strat. Units	Age	Fossils
	Alluvium	Quaternary	None Reported
	San Jose Formation	Early Eocene	Diverse vertebrate faunas of primitive mammals, turtles, crocodiles, fish, lizards, snake, and a bird. Some fresh water gastropods and unionids. Rare fossil leaves and some petrified wood.
	Nacimiento Formation	Early to middle Paleocene	Diverse vertebrate faunas of mammals, etc. Some fresh water invertebrates, wood and leaves.
	Ojo Alamo Sandstone	Earliest Paleocene	Rare fossil mammals. Much petrified wood.
	Kirtland Shale	Late Cretaceous	Dinosaurs, turtles, crocodiles, and other vertebrates. Leaves and wood locally abundant. Some fresh water invertebrates.
	Fruitland Formation	Late Cretaceous	Similar to Kirtland but also some brackish water inverts, and much fossil wood and leaves.
	Pictured Cliffs Sandstone	Late Cretaceous	Marine invertebrates and trace fossils.
	Lewis Shale	Late Cretaceous	Bivalves, ammonites, and other marine invertebrates. One mosasaur.
	Cliff House Sandstone	Late Cretaceous	Marine invertebrates and trace fossils, sharks teeth.
	Menefee Formation	Late Cretaceous	Fossil leaves and wood common. Rare vertebrates (mostly shark teeth and turtle scrap) and invertebrates.
	Point Lookout Sandstone	Late Cretaceous	Marine invertebrates and trace fossils, sharks teeth.

Lithology	Rock-Strat. Units	Age	Fossils
	Crevasse Canyon Formation	Cretaceous	Some fossil leaves and wood. Rare lower vertebrate and invertebrate fossils.
	Gallup Sandstone	Cretaceous	Marine inverts some fossil leaves
	Mancos Shale	Cretaceous	Great diversity of marine invertebrates, especially ammonites and bivalves.
	Dakota Sandstone	Lower(?) Cretaceous	Marine inverts, plants
	Morrison Formation	Late Jurassic	Some dinosaurs and petrified wood
	San Rafael Group	Jurassic	Marine invertebrates, fish in Todilto Limestone, rare fossil plants.
	Chinle Formation	Late Triassic	Plant and lower vertebrate fossils locally abundant.

Table 8

Estimated outcrop areas of the formations exposed in the Rio Puerco Resource Area.

Formation	Estimated Outcrop area (square miles)	Percentage of RPRA
Quaternary alluvium and Tertiary basalt	365	33
Zia Sand	1	<1
Galisteo Formation	2	<1
San Jose Formation		
poor exposures	57	5
good exposures	246	22
Nacimiento Formation	30	3
Ojo Alamo Sandstone	12	1
Kirtland Shale	5	<1
Fruitland Formation	8	<1
Pictured Cliffs Sandstone	5	<1
Lewis Shale	12	1
Mesa Verde Group	123	11
Mancos Shale	163	15
Dakota Sandstone	42	4
Jurassic rocks	21	2
Triassic rocks	8	1
Totals	1100	100

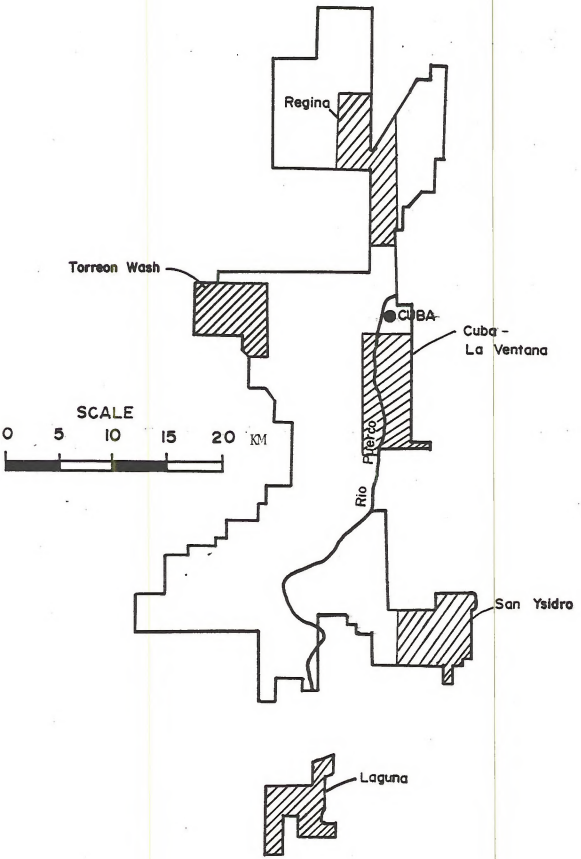


Figure 17. Critical areas in the Rio Puerco Resource Area.

The geologic history of this some 13,000 feet of sediment representing 200 million years of earth history is extremely complex and its summarization is beyond the scope of this report.

The format of this part of our report follows that of the previous part and reference is made here to general statements of philosophy and procedure already discussed.

PREVIOUS PALEONTOLOGICAL STUDIES

Unlike the SJPU, the RPRA has been the scene of intense paleontological study. At least three major collecting areas are present in the RPRA:

(1) Exposures of the San Jose Formation near Regina, Lindrith and Llaves have contributed virtually all the vertebrate fossils known from this formation. This is the area that yielded two classic North American Early Eocene faunas (Simpson, 1948b; Lucas, 1977).

(2) Nacimiento Formation outcrops along the cuestas in Torreon Wash. These outcrops contain the vertebrate fossils (i.e., mammals) considered to be the standard for the North American Middle Paleocene land mammal age "Torrejonian" (Wood, et al., 1941).

(3) Outcrops of the Mancos Shale south of Cuba as far as Cabezon include a key reference section of the Juana Lopez Member of the Mancos Shale (Dane, Cobban, and Kauffman, 1966). Fossiliferous exposures of several other members of the Mancos, especially the Semilla Sandstone Member (whose type section lies just outside of RPRA), have figured prominently in past studies of the Mancos (e.g., Lee, 1917; Renick, 1931; Cobban, 1951; Dane, Cobban, and Kauffman, 1966; Dane, Kauffman, and Cobban, 1968; Lamb, 1968).

Many other stratigraphic units in the RPRA also contain fossils, but in general their study has been sporadic and less intense than studies of the three collecting areas discussed above. For example, the Cliff House Sandstone, particularly the La Ventana Tongue, has been studied in some detail by Siemers and King (1974) and Mannhard (1976). In contrast, the Chinle Formation, known to contain many vertebrate and plant fossils outside the RPRA (e.g., Ash, 1972; Colbert, 1972; Stewart, Poole and Wilson, 1972) has been virtually unstudied in this area.

The history of paleontological collecting in a number of the stratigraphic units in the RPRA was summarized by Kues et al. (1977). This history is not included here because it is adequately treated by Kues et al. Faunal and floral lists for these units were given by Kues et al. (1977) and then reprinted with minor corrections by the U.S. Bureau of Land Management (1978). As in the case of the SJPU, it seems reasonable to assume that most taxa in the lists given by Kues et al. (1977) also are present in the study area.

Because only previously unstudied parts of the San Jose Formation were included in their study area, minor attention was given to that formation by Kues et al. (1977). To correct this, we here summarize the history of collecting in the San Jose Formation in the RPRA (Table 9). A revised faunal list of the vertebrates found in the San Jose within the RPRA is in Table 10. This table also points out taxa whose type specimens were found within the area.

CURRENT PALEONTOLOGICAL RESEARCH

Several scientists are currently conducting paleontological research in the Rio Puerco Resource Area and vicinity. They include:

1. Dr. S. C. Hook, New Mexico Bureau of Mines and Mineral Resources, Socorro, is studying the invertebrate faunas in the Semilla Sandstone and Juana Lopez Members of the Mancos Shale. He reports (written communication, 1979), that these faunas contain at least one new genus and two new species of ammonites.

2. Dr. Leonard Krishtalka, Carnegie Museum of Natural History, Pittsburgh, is presently investigating the record of vertebrate evolution preserved in the San Jose Formation of Eocene age. He indicates (written communication, 1979), that all of his localities are on private land near Regina and Lindrith.

3. Dr. Everett Lindsay, University of Arizona, Tucson, is researching vertebrate fossils and the magnetostratigraphy of certain formations in the area.

4. Mr. Costas Tsentas, a doctoral candidate in the Department of Anthropoplogy of New York University, is currently screenwashing a Paleocene fossil vertebrate locality in the Nacimiento Formation near Ojo Encino. The project began in the summer of 1979 during which time several tons of sediment were processed. It will continue into 1980 at which time Mr. Tsentas hopes to complete the fieldwork. The collection catalogued will be described in Mr. Tsentas doctoral dissertation, which he hopes to complete in 1981 or 1982. His specimens will ultimately be deposited in the collections of the Geology Department at the University of New Mexico.

Table 9

Summary of the history of paleontological work in the San Jose Formation in the Rio Puerco Resource Area

Dates	Worker(s)	Publications
1874	Cope	Cope, 1874; 1875a, 1875b, 1875c, 1876a, 1876b, 1876c, 1876d, 1876e, 1877, 1884.
1876-1888	Baldwin	Cope, 1882; Marsh, 1894; Thorpe, 1934.
1896	Wortman, Amer. Museum Exped.	Osborn, 1898.
1912-1913	Granger, Amer. Museum Exped.	Matthew, 1915a, 1915b, 1915c, 1918; Granger, 1914, 1915.
1936	Gazin, U.S. Nat. Mus. Exped.	Gazin, 1937.
1946-1958	Simpson, Amer. Museum Exped.	Simpson, 1948a, 1948b, 1950a, 1950b, 1951, 1954, 1955.
1970's	Univ. of Arizona (Lindsay) Univ. of New Mexico (Lucas)	Lucas, 1977

Table 10

Invertebrate and vertebrate taxa known from the San Jose Formation (from Cockerall, 1915 and Lucas and Manning, MS). Taxa whose genotype (**) or species type (*) came from the San Jose are indicated. The horizon from which the taxa have been reported, broken into "Almagre: (= most of the Regina Member) or Largo (= Tapicitas and Llaves members plus uppermost Regina Member) is indicated. For further explanation of the significance of the terms "Almagre" and "Largo" see Granger (1915), Simpson (1948B), Lucas (1977) and Lucas and Manning (MS).

Taxon	Types	Horizon
Invertebrata		
Class Gastropoda		
Campeloma calamodontis	*	?
Viviparus trochiformis		?
Vertebrata		
Class Osteichtyes		
Infraclass Neopterygii		
Family Lepisosteidae		
Atractosteus simplex		A,L
Class Amphibia (Anura)		
Unident, small frog		A
Class Reptilia		
Order Testudines		
Family Baenidae		
?*Baena arenosa*		?
Superfamily Testudinoidea		
Family Dermatemydidae		
Kallistira costilata	**	?
Family Emydidae		
Echmatemys cibollensis	*	A?
" *lativertebralis*	*	?
Family Testudinidae		
Geochelone (Manouria) majuscula	*	A?
Superfamily Trionychoiden		
Family Trionychidae		
Plastomenus catenatus	*	A?
" *communis*	*	A?
" *corrugatus*	*	A?
" (?) *fractus*	*	A?
" " *lacrymalis*	*	?
" " *leptomitus*	*	?
Amyda radula	*	A?
" (?) *ventricosa*	*	?

Taxon	Types	Horizon
Vertabrata (contd)		
Class Reptilia (contd)		
Order Squamata		
Family Anguidae		
cf. Peltosaurus		?
Paraghyptosaurus yatkoloi		A
Family Varanidae		
Saniwa sp.		A,L
Order Phidia		
Family Boidae		
cf. Helagras		?
Order Crocodilia		
Family Crocodylidae		
Crocodylus chamensis	*	?
" grypus	*	?
" wheelerii	*	?
" (?) elliotii		?
" " liodon		?
Orthosaurus sphenops	*	?
Class Aves		
Order Diatrymiformes		
Family Diatrymidae		
Diatryma gigantea	**	?
Class Mammalia		
Order Marsupialia		
Family Didelphidae		
Peratherium comstocki (?)		A
Unident. small didelphid		A
Order Edentata (?)		
Family Metacheiromyidae		
(?) Palaeanodon		?
Order Deltatheridia		
"Family Palaeoryctidae"		
Didelphodus absarakae		A
Family Hyaenodontidae		
Prototomus viverrinus	**	?
" multicuspis	*	?
" (?) secundarius	*	?
Tritemnodon strenua	*	?
" hians	*	A
Family Oxyaenidae		
Subfamily Limnocyoninae		
Prolimnocyon atavus		?
Subfamily Oxyaeninae		
Oxyaena lupina	**	A,L
" forcipata	*	A
" simpsoni	*	L
Subfamily Palaeonictinae		
Ambloctonus sinosus	**	L?
" hyaenoides	*	L

Taxon	Types	Horizon
Vertabrata (contd)		
Class Mammalia (contd)		
Order Carnivora		
"Family Miacidae"		
"Subfamily Miacinae"		
Ogdectes sp.		A
Uintacyon m. massetericus		A
Vulpavus australis	*	A,L
Miacis df. parvivorus		A
Subfamily Viverravinae		
Didymictis p. protenus	**	A,L
Order Taeniodonta		
Family Stylinodontidae		
Ectoganus gliriformis	**	?
" simplex	*	?
Order Tillodontia		
Esthonyx bisculcatus	**	A,L
Order Pantodonta		
Family Coryphodontidae		
Coryphodon radians		A
" armatus		A,L
" elephantopus	*	A
" cuspidatus	*	A
" latidens	*	A
" lobatus	"	A
" testis		A
Order Insectivora, sensu stricto		
Family Adapisoricidae (Erinacebid)		
Scenopagus curtidens		?
Diacodon alticuspis	**	A
Macrocranion nitens		A
Family Nyctitheriidae		
Leptacodon catulus	*	A
Nyctitherium serotinum		?
Order Insectivora, sensu lato		
Family Apatemyidae		
Apatemys bellus		A
Family Leptictidae		
Prodiacodon tauricinerei		A
Family Palaeosinopa		
Palaeosinopa didelphoides		A
Family Apheliscidae		
Apheliscus insidiosus	**	?
Order Primates, sensu lato		
"Family Paramomyidae"		
Phenacolemur jepseni	*	A
Family Microsyopidae		
Subfamily Microsyopinae		
Microsyops wilsoni		?
" angustidens		L
" latidens		A,L

Taxon	Types	Horizon
Vertebrata (contd)		
Class Mammalia (contd)		
Subfamily Uintasoricinae		
Navajovius mckennai	*	A
Order Primates, sensu stricto		
Family Adapidae		
Pelycodus frugivorus	*	A,L
" jarrovii	**	A
Copelemur tutus	**	A,L
" consortutus		?
Family Omomyidae		
Subfamily Omomyinae (Uintaniini)		
Uintanius vespertinus		A
Order Rodentia		
"Family Paramyidae"		
Paramys C. copei		L
" c. bicuspis		A,L
" excavatus taurus		A
aff. Leptotomus costillo		A
Thisbemys nini	*	L
Franimys buccatus	*	?
Family Sciuravidae		
cf. Sciuravus sp.		A
Unident. sciuravine		
"Superorder Ungulata"		
Family Arctocyonidae, sensu stricto		
Chriacus gallinae	*	A
Anacodon ursidens		A
Thryptacodon australis		A
Family Hyopsodontidae		
Hyopsodus miticulus	*	A,L
Hyopsodus wortmani (?)		?
Family Mesonychidae		
Pachyaena ossifraga	**	A
Family Phenacodontidae		
Phenacodus brachypternus		A,L
" vortmani		A
" primaevus		A
Family Meniscotheriidae		
Meniscotherium chamense	**	A,L
" tapiacitum	*	?
Order Perissodactyla		
Family Equidae		
Hyracotherium index		A
" vasacciense		A,L
" tapirinium	*	A,L
Order Artiodactyla		
Family Entelodontidae		
Diacodexis chacensis	*	A,L
" cf. secans		A
Bunophorus dorseyanus		A
" grangeri		A,L

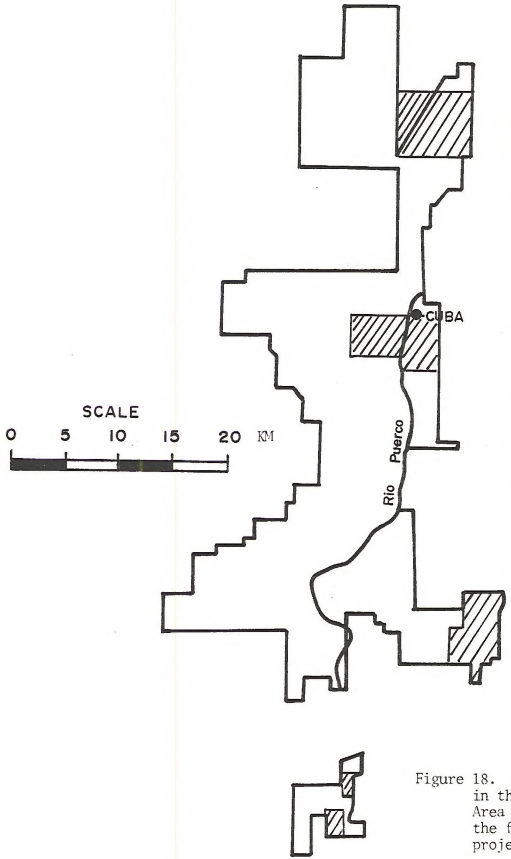


Figure 18. Principal areas (hatched) in the Rio Puerco Resource Area surveyed by our team during the field work phase of the project.

PRESENT STUDY

During the present study, the entire RPRA was reconnoitered but only selected areas, including the critical areas (Fig. 17), were surveyed. These surveyed areas (Fig. 18) and the rationale justifying their survey are as follows:

(1) Regina critical area. The classic San Jose Formation outcrops (see discussion under "Previous Study of the RPRA") in the Regina critical area (Fig. 17) were originally studied by Cope, Granger and Simpson and have produced the type specimens of 55 vertebrate species (Table 10). We felt that some survey was necessary to determine whether this area, intensively collected in the past, is still fossiliferous.

(2) Cuba-La Ventana area. Outcrops of a number of Cretaceous formations (Mancos Shale, Point Lookout Sandstone, Menefee Formation, Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, and Kirtland/Fruitland Formation) between Cuba and La Ventana were sampled to gain an idea of the relative productivity of these different stratigraphic units.

(3) San Ysidro area. A partial skeleton of the sauropod dinosaur Camarasaurus supremus was recently collected by J. Keith Rigby, Jr. of the BLM from the Morrison Formation a few miles southwest of San Ysidro. This is the first such skeleton to be discovered in the Morrison Formation in New Mexico. This area was surveyed to determine whether or not other dinosaur remains were present in this area.

(4) Area northeast of Laguna. Outcrops of the Morrison Formation, Dakota Sandstone, and Mancos Shale in this area are a favorite hunting ground for amateur collectors and rockhounds. The area is particularly noted for large ammonites. We examined this area to determine which stratigraphic units and outcrops are producing these fossils.

Our fieldwork turned up 103 localities, broken down according to location and level of significance in Table 11. The results of the fieldwork combined with the literature search represent as thorough an inventory of the paleontological resources of the RPRA as is possible given the amount of time available. Nevertheless, we recommend that the extensive badlands of the Mancos Shale, Point Lookout Sandstone, and Menefee Formation between Cabezon and Torreon, deserve further survey. This area has been studied by other workers (e.g., Lee, 1912, Cobban, 1951, Mannhard, 1976) who have reported many occurrences of marine invertebrates in these strata. Amateur collectors have collected widely in this area for ammonities as well as other invertebrates.

CURRENT LAND USE

As in the survey of the SJPU, one of the objectives of our fieldwork was to observe and document land use activities in the RPRA that are at present adversely affecting paleontological resources or are likely to adversely affect them in the future. The major types of land use activity in the RPRA that fit this description are the same as those encountered in the SJPU with the exception of dams and reservoirs, of which there are presently none in the RPRA.

Some of these land use activities observed by us in the RPRA are illustrated in Figure 19. A rating of the impact of land use activities on the paleontological resources in the RPRA is given in Table 12. Table 13 is our evaluation of the present significance of these adverse land use activities in the critical areas identified by the Bureau of Land Management in the RPRA (Fig. 17).

Table 11

Summary of the significance level of localities found in the Rio Puerco Resource Area during the present survey. See Table 4 for an explanation of significance levels.

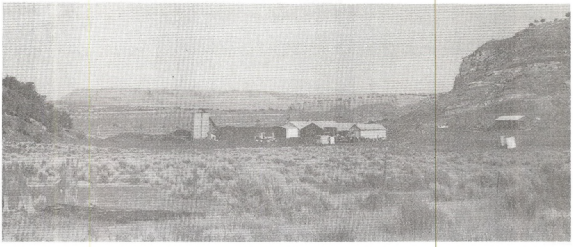
Significance Level	Number of Localities
1	14
2	16
3	73

Figure 19. Land use activities in the Rio Puerco Resource Area.

A. Humate mine in the Upper Cretaceous Menefee Formation between Cuba and La Ventana. Mesa Portales in the background.

B. Gypsum mine in the Upper Jurassic Todilto Formation at White Mesa south of San Ysidro.

C. Gas well and pipeline in the early Eocene San Jose Formation north of Lindrith.



A

B

C

FIGURE 19. Land use activities, RPRA

Table 12

Rating of land use activities in the Rio Puerco Resource Area

Land Use Activity	General impact on Paleontological Resources	Comments
1) Grazing and related construction	low	Only impacts when stock tanks or roads built through outcrops containing fossils.
2) Road building	moderate	High if built through outcrops containing fossils.
3) Off road vehicles	moderate	Often crosses outcrop so has great potential to be of high impact.
4) Mining	moderate-high	Generally only on alluvial covered surfaces but high if in rocks containing fossils.
5) Powerline and pipeline corridors	moderate	Similar to road building.
6) Drill pads	moderate	When built on outcrop very destructive of relatively large area surrounding drill hole.
7) Urban expansion	high	Results in increases in almost all other forms of land use that have an adverse affect on fossils.
8) Dumps and landfills	low	Usually constructed in or on alluvial but if built on rocks containing fossils the impact will be high

Table 13

Evaluation of land use activities in critical areas of the Rio Puerco Resource Area

(See Table 6 for explanation of symbols.)

Land Use Activity	Regina Area	Laguna Area	Cuba-La Ventana	San Ysidro Area	Torreon Wash
1. Grazing	x	-	x	-	x
2. Road building	x	-	x	-	-
3. Off road driving	-	-	x	-	x
4. Mining	-	-	x	x	-
5. Powerlines and pipelines	x	-	-	-	-
6. Drill pads	x	-	-	-	-
7. Urban expansion	-	-	-	-	-
8. Dams and reservoirs	-	-	-	-	-
9. Dumps and landfills	x	-	-	-	-

MITIGATION AND MANAGEMENT SUGGESTIONS

Philosophy

Our philosophy regarding mitigation and management of paleontological resources in the RPRA is the same as that presented earlier for the SJPU. The following are site specific mitigation and management suggestions for areas in the RPRA that are paleontologically significant.

Areas Requiring Mitigation

Our survey has identified six areas in the RPRA that we feel require mitigation (Fig. 20):

(1) Regina Critical area. As mentioned above, this is the area which produced all of the classic vertebrate collections of Cope, Granger, and Simpson from the San Jose Formation. Our survey revealed that outcrops in this area are extremely fossiliferous. In fact, they are the most fossiliferous in the entire San Jose Formation and occur in an area of some 30 square miles.

The area is readily accessible and one of us (SGL) knows a number of amateur collectors in Albuquerque who regularly collect here and have acquired excellent specimens. Our survey revealed a number of localities that are suitable for screenwashing. Screenwashing has been essentially neglected by previous collectors in the San Jose Formation (Lucas, 1977), therefore, these localities are especially important.

We suggest a salvage operation involving the screenwashing of these sites be undertaken as soon as possible. A three or four month project involving test sampling of the localities followed by intensive screening of those localities determined to be worthy of further screening (see discussion of mitigation of the Santos Peak area in previous section)

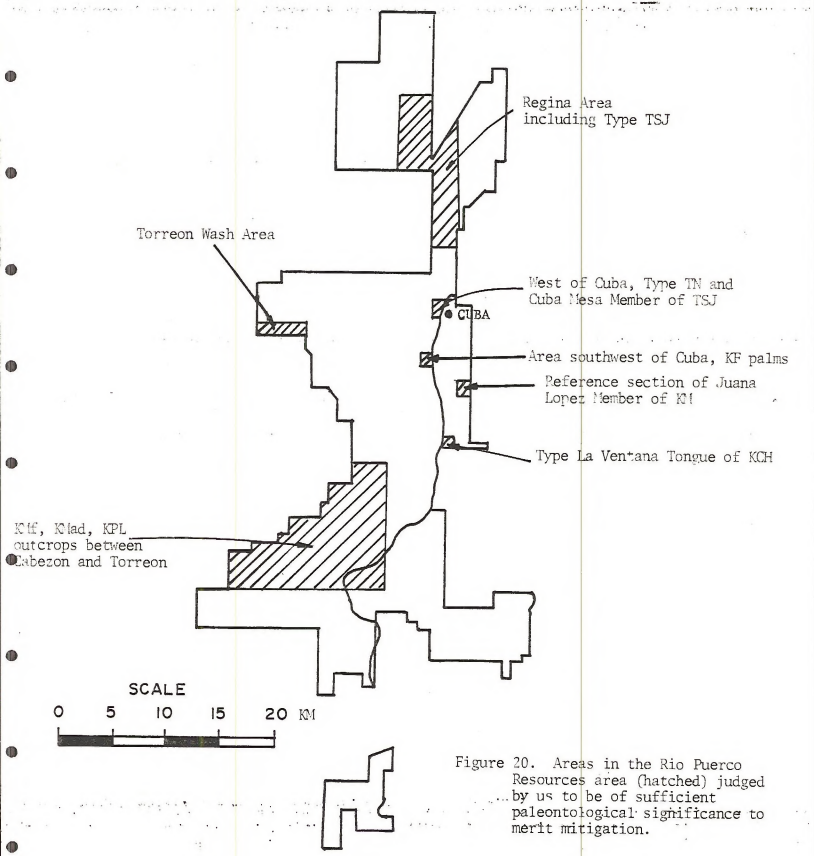


Figure 20. Areas in the Rio Puerco Resources area (hatched) judged by us to be of sufficient paleontological significance to merit mitigation.

supervised by an experienced vertebrate paleontologist would suffice. Further surface collecting in the area might also be undertaken, but we feel that the emphasis should be on screenwashing.

As a final note on this area we should point out that the type area of the San Jose Formation (Simpson, 1948b) and the type sections of three of its members--Regina Member, Llaves Member, Tapicitos Member (Baltz, 1967)--are in this area or adjacent to it. These type localities (Figs. 21B, 22) should, for the reasons expressed earlier, be preserved intact and not be allowed to be altered by mining, road building, or other destructive activities.

(2) Area west of Cuba. The type section of the Cuba Mesa Member of the San Jose Formation (Baltz, 1967) and the type section of the Nacimiento Formation (Baltz, 1967), both near Cuba, should of course, be preserved intact (Fig. 21A, C).

(3) Areas northeast of La Ventana. The type section of the La Ventana Tongue of the Cliff House Sandstone (Fig. 28A) and a highly fossiliferous reference section of the Juana Lopez Member of the Mancos Shale (Dane, Cobban, and Kauffman, 1966) northeast of La Ventana should also be preserved intact (Fig. 23B).

(4) Area southwest of Cuba. Our survey discovered a large field of fossil palm logs and stumps in the Fruitland Formation a few miles south of Cuba (Fig. 24C, D). This locality is a very rare occurrence for the Late Cretaceous, an absolutely unique occurrence for the Fruitland Formation, and thus is of great scientific importance.

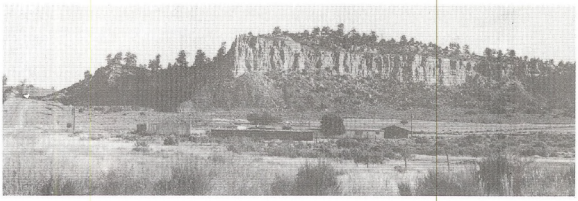
We recommend that nothing be done to this locality except insure that a paleobotanist studies the occurrence as soon as possible. The palms, mostly buried by alluvium or embedded in the Fruitland, are fairly obscure.

Figure 21. Type areas of Lower Tertiary stratigraphic units in the Rio Puerco Resource Area.

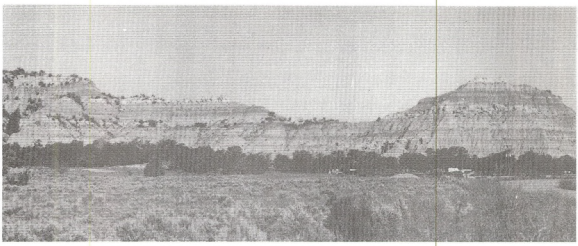
A. Typical exposure of the lower part of the Cuba Mesa Member of the San Jose Formation northwest of Cuba. The type section of the member was measured along State Highway 44 (left side of photograph).

B. Type locality of the San Jose Formation about a mile northwest of Regina. The rocks in this view are assigned to the Regina Member of the formation.

C. Type locality of the Nacimiento Formation (steep slopes) and the base of the overlying San Jose Formation (cliff) on the south end of Mesa de Cuba.



A



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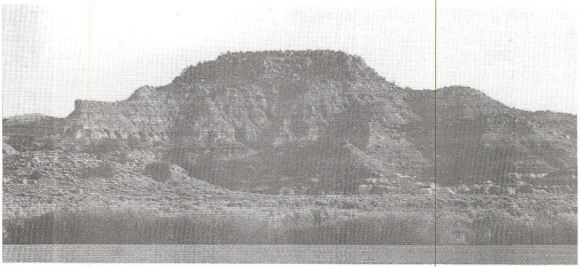


C

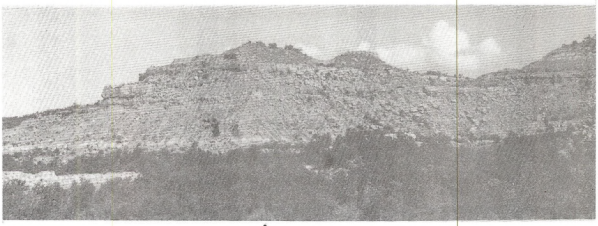
FIGURE 21. Lower Tertiary Rocks, RPRA

Figure 22. Type sections of the San Jose Formation in or near the Rio Puerco Resource Area.

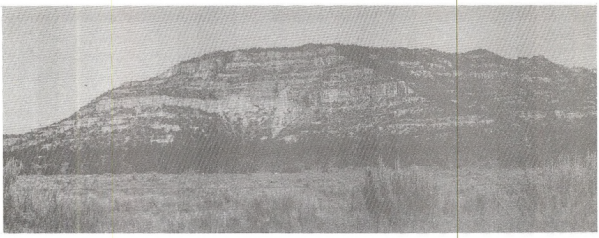
A. Type section of the Tapicitos Member of the San Jose Formation near State Highway 95 along upper Gavilan creek.

B. Type section of the Llaves Member of the San Jose Formation about 1-1/2 miles northwest of Llaves Post Office at the mouth of Canoncito de las Yeguas.

C. Type section of the Regina Member of the San Jose Formation about 2 miles southwest of Llaves Post Office.



A



B

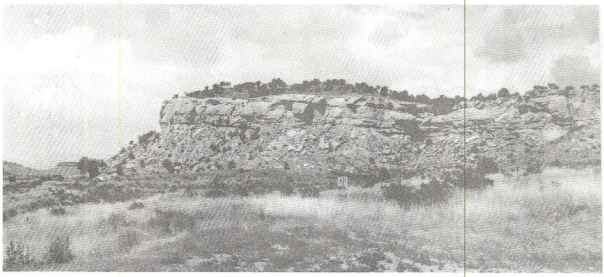
C

FIGURE 22. San Jose Formation, RPRA

Figure 23. Type areas of Upper Cretaceous stratigraphic units in the Rio Puerco Resource Area between Cuba and La Ventana.

A. La Ventana Tongue of the Cliff House Sandstone in the type area just east of the settlement of La Ventana.

B. Reference section of the Juana Lopez Member of the Mancos Shale a few miles northeast of La Ventana.



A

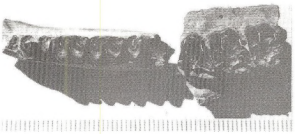
B

FIGURE 23. Upper Cretaceous Rocks, RPRA

Figure 24. Upper Cretaceous plant fossils and Eocene mammal teeth from the Rio Puerco Resource Area.

A,B. Meniscotherium chamense. Left mandible (left) and maxilla (right). A, occlusal view. B, lateral view. Tapicitos Member of the San Jose Formation. No. E90-1. Scale is in millimeters.

C,D. Palmoxylon sp. Two fine trunks. Fruitland Formation south of Cuba. C, a trunk after it was cleaned and reconstructed in the laboratory. It is about 1.25 meters tall. No. B177-1. D, a trunk partially imbedded in rock. This specimen is about 80 cm long. No. B177-2.



A

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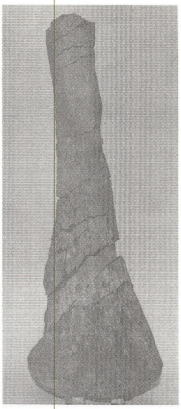

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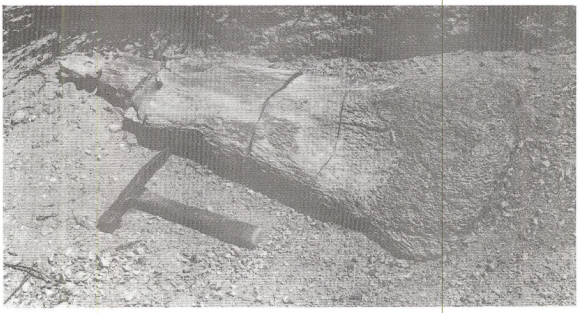

D

FIGURE 24. Upper Cretaceous and Eocene Fossils

Figure 25. Plant fossils from the Upper Cretaceous Menefee Formation in the Rio Puerco Resource Area. The scale in each photograph is in millimeters.

A. Araucaria formosa. Portion of a leafy shoot near the apex. This fossil is common in certain Upper Cretaceous rocks in western North America associated with coal-forming environments. No. B181-3.

B. Protophyllocladus polymorpha (upper portion of a phyllode) on the left and Sequoia cuneata (leafy shoot) on the right. P. polymorpha is a common conifer in Upper Cretaceous rocks in western and midwestern North America which were deposited in coal-forming environments. S. cuneata is a redwood which commonly occurs in western North America. It is generally restricted to rocks deposited in coal-forming environments.

C. Laurophyllum candatum. Upper portion of the blade showing the strong midrib and the dichotomous venation characteristic of this species. No. B179-5.

D. Ficus praetinervis. Most of the leaf blade is present but the margin is missing. No. B179-33.

E. Viburnum speciosum. Leaf blade without the apex and base. No. B179-39.

F. Cissus marginata. Upper portion of leaf blade with an incomplete margin on the right. This fossil is common in Upper Cretaceous rocks which were deposited in bottomlands and in coal-forming environments in western North America. No. B179-39.

G,H. Cercidiphyllum arcticum. Leaf blade. The petiole is absent in G. This species is common in Upper Cretaceous rocks which were deposited in bottomlands but is absent in rocks deposited in coal-forming environments. G. No. 179-32, H. No. 171-11.

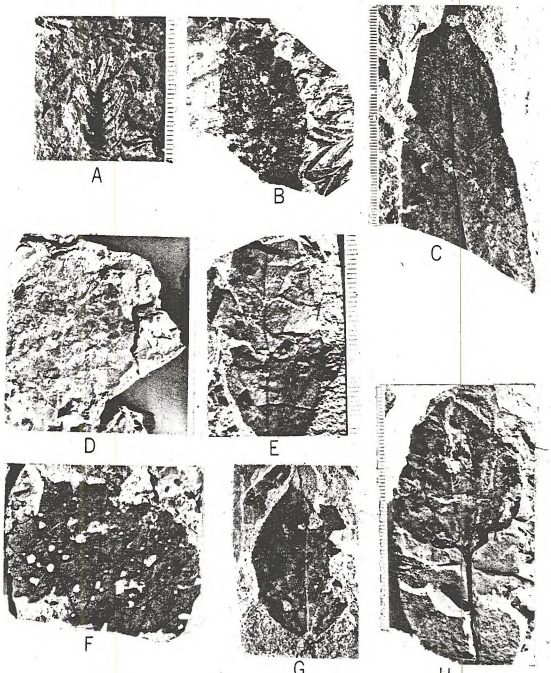

FIGURE 25. Upper Cretaceous Plant Fossils, RPRA

The Bureau of Land Management's previous policy of posting signs forbidding the collection of fossil wood and closing roads in the area will do little more than attract attention to this locality and promote its destruction by rockhounds and amateur collectors.

After the study of the locality by a paleobotanist, it may be possible, pending the paleobotanist's report, to collect a few good specimens suitable for display.

The Menefee Formation in this area also yielded many compressed leaves including the following forms:

Conifers

Sequoia cuneata
Protophyllocladus polymorpha
Araucaria formosa

Angiosperms

Cercidiphyllum arcticum
Cissus marginata
Viburnum speciosum
Ficus praetrinervis
Laurophyllum caudatum
Phyllites sp.

Examples of several of these fossils are shown in Figure 25. This new locality of the Menefee flora should be investigated.

(5) Torreon Wash. The Nacimiento Formation in the Torreon Wash area contains fossils that were the primary basis for the designation of the Middle Paleocene "Torrejonian" [sic] North American land mammal "age" (Wood et al., 1941). As such, the area assumes great importance in addition to that imparted by the extraordinarily fossiliferous beds it encompasses. It is, in effect, a type area, and the same unqualified preservation urged for other type sections should apply.

We did not need to spend survey time in the area because Mr. Costas Tsentas, a graduate student at New York University presently working on Paleocene mammals

from Torreon Wash for his dissertation, has informed us that the area is still quite fossiliferous. This is also evident from the Kues et al. (1977) report. We recommend that the BLM preserve the area intact and not conduct any salvage or further survey until completion of Mr. Tsentas' work. At that time (probably in 1980) the BLM should contact him for suggestions as to how any further survey and salvage should be conducted in the area. We strongly urge that the BLM add the Torreon Wash area to its list of "Paleontological Preserves" as recommended by Kues et al. (1977).

(6) Area between Cabezon and Torreon Wash. A large and essentially unexplored area of highly dissected badlands of the Mancos Shale, Point Lookout Sandstone, and Menefee Formation is present between Cabezon and Torreon. Unfortunately our fieldwork was not scheduled to include survey of these outcrops, but we feel that a survey of them would be worthwhile. A one to two month survey by a ten man crew with the aim of discovering new localities in this area is recommended. Until such a survey, no major land use activities destructive to fossils should be permitted in this area.

Our survey did not determine any areas worthy of mitigation of paleontological resources in the RPRA outside of those discussed above. A summary of our mitigation and management suggestions for the paleontologically significant areas in RPRA is contained in Table 14. We recommend that the San Ysidro and Laguna areas not be considered as paleontologically critical areas. Rather, we suggest that attention be directed in the form of further survey, salvage or preservation towards the six areas we have identified as shown in Table 14.

Table 14

Summary of Mitigation and Management Suggestions
for Paleontologically Significant Areas
in the Rio Puerco Resource Area

Area	Formation	Nature of Occurrences	Mitigation and Management Suggestions
Regina Critical	San Jose Formation	Abundant fossil vertebrate localities (especially mammals) including small vertebrate accumulations.	Salvage of small vertebrate localities by screenwashing (3-4 months) under the supervision of a vertebrate paleontologist. Further surface collecting for several months.
West of Cuba	Nacimiento Formation	Type section of rock-stratigraphic unit.	Preservation of type section. Prevent destruction by industrial and other activities.
Northeast of La Ventana	Cliff House Sandstone, Mancos Shale	Type section of rock-stratigraphic unit	Preservation of type section. Prevent destruction by industrial and other activities.
Southwest of Cuba	Fruitland Formation	Large field of fossil palm logs and stumps.	Insure that a paleobotanist studies this occurrence in situ before it is collected
	Menefee Formation	Fossil leaves.	Further collecting by a paleobotanist.
Torreon Wash	Nacimiento Formation	Abundant fossil mammals and other vertebrates, "type" area for Torrejonian land mammal "age".	Designate a "Paleontological Preserve" in consultation with Tsentas (NYU) who is presently undertaking research in this areas.
Between Cabezon and Torreon Wash	Mancos, Point Lookout, Menefee Formations	Extensive badlands, essentially unstudied	Intensive survey by a ten-man crew (1-2 months) under the supervision of a paleontologist.

Summary

During the course of this survey 88 localities containing generically identifiable fossils were found in the SJPU. Three areas were noted which require mitigation: 1) the area near Santos Peak where the first plant fossils known from the San Jose Formation were discovered by members of our survey crew. Several possible screening sites were also discovered in this unit in that area. 2) The Kutz Canyon area where the Nacimiento Formation continues to yield important Paleocene mammal fossils, and 3) the area west of Farmington where the type localities of the Fruitland Formation, Kirtland Shale, and the Pictured Cliffs Sandstone occur. The Bohannon Canyon and Lybrook areas do not appear to be sufficiently fossiliferous to retain the designation of "critical areas."

Six areas were noted in the RPRA which will require mitigation. They are: 1) the Regina Critical Area where the San Jose Formation continues to yield large quantities of mammal remains. 2) the area west of Cuba where the type sections of the Cuba Mesa Member of the San Jose Formation and of the Nacimiento Formation are exposed. 3) the highly fossiliferous reference section of the Juana Lopez Member of the Mancos Shale northeast of La Ventana. 4) the area a few miles southwest of Cuba where many palm axes and bases occur in the Fruitland Formation. 5) the Torreon Wash area where the Nacimineto Formation contains many important vertebrate fossils. 6) the area between Cabezon and Torreon Wash where the marine Cretaceous rocks contain many invertebrate fossils particularly ammonites. We recommend that the San Ysidro and Laguna areas not be considered critical any longer as they appear to be less fossiliferous than the others listed above.

REFERENCES CITED

ASH, S. R., 1972.
Plant megafossils of the Chinle Formation.
Mus. Northern Ariz. Bull., 47:23-44.

BALTZ, E. H., JR., 1967.
Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan Basin, New Mexico.
U.S. Geol. Surv. Prof. Paper, 52:1-101.

BALTZ, E. H., JR., S. R. ASH AND R. Y. ANDERSON, 1966.
History of nomenclature and stratigraphy of rocks adjacent to the Cretaceous-Tertiary boundary western San Juan Basin, New Mexico.
U.S. Geol. Surv. Prof. Paper, 524-D:1-23.

BAUER, C. M., 1916.
Stratigraphy of a part of the Chaco River Valley.
U.S. Geol. Surv. Prof. Paper, 98:271-278.

COBBAN, W. A., 1951.
Scaphitoid cephalopods of the Colorado Group.
U.S. Geol. Surv. Prof. Paper, 239:1-42.

COCKERELL, T. D. A., 1915.
Tertiary mollusca from New Mexico and Wyoming.
Amer. Mus. Nat. Hist. Bull., 33:101-107.

COLBERT, E. H., 1972.
Vertebrates from the Chinle Formation.
Mus. Northern Ariz. Bull., 47:1-12.

COPE, E. D., 1874.
Notes on the Eocene and Pliocene lacustrine formations of New Mexico, including descriptions of certain new species of vertebrates.
Annual report . . . surveys most of the 100th meridian (Wheeler Survey):115-130.

COPE, E. D., 1975a.
The Vertebrata of the Cretaceous formations of the West.
U.S. Geol. Survey Terr. (Hayden) Rept., 2-303.

COPE, E. D., 1875b.
Systematic catalogue of Vertebrata of the Eocene of New Mexico collected in 1874.
U.S. Geol. Surveys west of the 100th meridian (Wheeler Survey). 37 p.

COPE, E. D., 1875c.
Reports on the geology of that part of northwestern New Mexico examined during the field season of 1874.
Annual report . . . Surveys west of the 100th meridian (Wheeler Survey):61-97.

COPE, E. D., 1876a.
On the supposed Carnivora of the Eocene of the Rocky Mountains.
Acad. Nat. Sci. Phila. Proc., 1875:444-448.

COPE, E. D., 1876b.
On a gigantic bird from the Eocene of New Mexico.
Acad. Nat. sci. Phila. Proc., 1876:63-68.

COPE, E. D., 1876c.
On the Taeniodonta, a new group of Eocene Mammalia.
Acad. Nat. Sci. Phila. Proc., 1876:39.

COPE, E. D., 1876d.
On the geologic age of the vertebrate fauna of the Eocene of New Mexico.
Acad. Nat. sci. Phila. Proc., 1876:63-66.

COPE, E. D., 1876e.
On some supposed lemurine forms of the Eocene Period.
Acad. Nat. Sci. Phila. Proc., 1876:88-89.

COPE, E. D., 1877.
Report upon the extinct vertebrates obtained in New Mexico by parties
of the expedition of 1874.
Geog. Survey west of the 100th meridian (Wheeler Survey), pt. 2:1-370.

COPE, E. D., 1882.
Some new Forms from the Puerco Eocene.
Amer. Nat., 16:833-834.

COPE, E. D., 1884.
The Vertebrata of the Tertiary formations of the West.
U.S. Geol. Survey Terr. (Hayden) Rept. 3:1-1009.

COPE, D. D., 1886.
The Plagianlacidae of the Puerco Epoch.
Amer. Nat., 20:451.

DANE, C. H. AND G. O. BACHMAN, 1965.
Geologic map of New Mexico.
U.S. Geol. Surv., Map Scale 1:500,000.

DANE, C. H., W. A. COBBAN AND E. G. KAUFFMAN, 1966.
Stratigraphy and regional relationships of a reference section
of the Juana Lopez Member of the Mancos Shale in the San Juan
Basin, New Mexico.
U.S. Geol. Surv. Bull., 1224-H:1-15.

DANE, C. H., E. G. KAUFFMAN AND W. A. COBBAN, 1968.
Semilla Sandstone, a new member of the Mancos Shale in the southeastern
part of the San Juan Basin, New Mexico.
U.S. Geol. Surv. Bull., 1245-F:1-21.

FASSETT, J. E. AND J. S. HINDS, 1971.
Geology and fuel resources of Fruitland Formation and Kirtland Shale of the
San Juan Basin, New Mexico and Colorado.
U.S. Geol. Surv. Prof. Paper, 676.

GAZIN, C. L., 1937.
Hunting for fossils in the Navajo country.
Explorations and Fieldwork of the Smiths. Inst. 1936:19-22.

GRANGER, W., 1914.
On the names of lower Eocene faunal horizons of Wyoming and New Mexico.
Amer. Mus. Nat. Hist. Bull., 33:201-207.

GRANGER, W., 1915.
A revision of the lower Eocene Wasatch and Wind River faunas. Part III--Order Condylarthra. Families Phenacodontidae and Meniscotheriidae.
Ibid.:329-361.

GRANGER, W., 1917.
Notes on Paleocene and lower Eocene mammal horizons of northern New Mexico and southern Colorado.
Amer. Mus. Nat., Hist. Bull., 37:821-830.

GRANGER, W., AND SIMPSON, G. G., 1928.
Multituberuclata in the Wasatch Formation.
Amer. Mus. Nat. Hist. Novitates 312:1-14.

GRANGER, W., AND SIMPSON, G. G., 1930.
A revision of the Tertiary Multituberculata.
Amer. Mus. Nat. Hist. Bull., 56:601-676.

HOLMES, W. H., 1877.
Geological report on the San Juan District.
U.S. Geol. and Geog. Surv. Terr. (Hayden), Ann Report for 1875:237-276.

KAY, R. F. AND M. CARTMILL, 1974.
Skull of Palaechthon nacimienti.
Nature, 252:37-38.

KAY, R. F. AND M. CARTMILL, 1977.
Cranial morphology and adaptations of Palaechthon nacimienti and other Paromomyidae (Plesiadapoidea (?) Primates), with a description of a new genus and species.
Jour. Human Evol., 6:19-53.

KUES, B. S., J. W. FROEHLICH, J. A. SCHIEBOUT AND S. G. LUCAS, 1977.
Paleontological survey, resource assessment, and mitigation plan for the Bisti-Star Lake Area, northwestern New Mexico.
U.S. Bur. Land Management, Albuquerque, N.M.:1-399.

LAMB, G.M., 1968.
Stratigraphy of the lower Mancos Shale in the San Juan Basin.
Geol. Soc. Amer. Bull., 79:827-854.

LEE, W. T., 1912.
Stratigraphy of the coal fields of northern central New Mexico.
Geol. Soc. Amer. Bull., 23:571-686.

LEE, W. T., 1917.
Geology of the Raton Mesa and other regions in Colorado and New Mexico.
U.S. Geol. Surv. Prof. Paper, 101:9-221.

LINDSAY, E. H., L. L. JACOBS AND R. F. BUTLER, 1978.
Biostratigraphy and magnetostratigraphy of Paleocene terrestrial deposits, San Juan Basin, New Mexico.
Geol., 6:425-429.

LUCAS, S. G., 1977.
Vertebrate paleontology of the San Jose Formation, east-central San Juan Basin, New Mexico.
New Mexico Geol. Soc. Guidebook, 29th Field Conf., 221-224.

MANNHARD, G. W., 1976.
Stratigraphy, sedimentology and paleoenvironments of the La Ventana Tongue of the Mesa Verde Group (Upper Cretaceous), southeastern San Juan Basin, New Mexico.
Unpubl. Ph.D. dissertation, Univ. New Mexico, 182 p.

MARSH, O. C., 1894.
Description of Tertiary antiodactyls.
Amer. Jour. Sci., 48:259-274.

MATTHEW, W. D., 1915a.
A revision of the lower Eocene Wasatch and Wind River faunas. Part I--Order Ferae (Carnivora). Suborder Creodonta.
Amer. Mus. Bull., 34:4-103.

MATTHEW, W. D., 1915b.
A revision of the lower Eocene Wasatch and Wind River faunas. Part II--Order Condylarthra. Family Hyopsodontidae.
Amer. Mus. Bull., 34:311-328.

MATTHEW, W. D., 1915c.
A revision of the lower Eocene Wasatch and Wind River faunas. Part III--Order condylarthra. Families Phenacodontidae and Meniscotheriidae.
Amer. Mus. Nat. Bull., 34:329-361.

MATTHEW, W. D., 1918.
A revision of the lower Eocene Wasatch and Wind River faunas. Part V--Insectivora (continued). Glire, Edentata.
Amer. Mus. Nat. Bull., 38:565-657.

MATTHEW, W. D., 1937.
Paleocene faunas of the San Juan Basin, New Mexico.
Amer. Philos. Soc. Trans., 30:1-374.

McKENNA, M. C., 1962.
Collecting small fossils by washing and screening.
Curator, 5:221-235.

OSBORN, H. F., 1898.
A complete skeleton of Coryphodon radians; notes upon the locomotion of this animal.
Amer. Mus. Nat. Hist. Bull., 10:81-92.

OSBORN, H. F. AND C. EARLE, 1895.
Fossil mammals of the Puerco beds.
Amer. Mus. Nat. Hist. Bull., 7:1-70.

REESIDE, J. B., JR., 1924.
Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin of Colorado and New Mexico.
U.S. Geol. Surv. Prof. Paper, 134.

RENICK, B. C., 1931.
Geology and groundwater resources of western Sandoval County, New Mexico.
U.S. Geol. Surv. Water Supply Paper, 620:1-117.

SIEMERS, C. T. AND N. R. KING, 1974.
Macroinvertebrate paleoecology of a transgressive marine sandstone. Cliff House Sandstone (Upper Cretaceous) Chaco Canyon, northwestern New Mexico.
New Mexico Geol. Soc., 25th Field Conf. Guidebook:267-277.

SIMONS, E. L., 1963.
David Baldwin, O. C. Marsh and the discovery of the first continental Paleocene faunas of the New World.
Postilla, 75:1-11.

SIMPSON, G. G., 1948a.
A fossil collecting campaign in New Mexico.
Science, 107:207-212.

SIMPSON, G. G., 1948b.
The Eocene of the San Juan Basin, New Mexico.
Amer. Jour. Sci., 246:257-292, 363-385.

SIMPSON, G. G., 1950a.
Cenozoic formations and vertebrate faunas.
Guidebook 4th Field Conf. Soc. Vert. Paleo. northwestern New Mexico,:74-85.

SIMPSON, G. G., 1950b.
Lower Tertiary formations and vertebrate faunas of the San Juan Basin.
New Mexico Geol. Soc. 1st Field Conf. Guidebook:85-89.

SIMPSON, G. G., 1951.
Hayden, Cope and the Eocene of New Mexico.
Acad. Nat. Sci. Phila. Proc., 103:1-21.

SIMPSON, G. G., 1954.
An apatemyid from the early Eocene of New Mexico.
Amer. Mus. Nov., 1654:104.

SIMPSON, G. G., 1955.
The Phenacolemuridae, new family of early primates.
Amer. Mus. Nat. Hist. Bull., 105:411-442.

SINCLAIR, W. J., 1914.
"Laramie?", Puerco and Torrejonian in the San Juan Basin, New Mexico.
Geol. Soc. Amer. Bull., 25:138.

SINCLAIR, W. J. AND W. GRANGER, 1914.
Paleocene deposits of the San Juan Basin, New Mexico.
Amer. Mus. Nat. Hist. Bull., 33:297-316.

STEWART, J. H., F. POOLE AND R. WILSON, 1972.
Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado plateau region.
U.S. Geol. Surv. Prof. Paper, 690:1-336.

THORPE, M. R., 1934.
Meniscotherium robustum sp. nov. and a discussion of Hyracops socialis Marsh.
Amer. Jour. Sci., 5th Ser., 27:401-409.

U.S. BUREAU OF LAND MANAGEMENT, 1978.
Draft Star Lake-Bisti Regional coal environmental Statement, Part I, Regional Analysis; Part 2, Site Specific Analysis; Part 3, Appendices B, C, D.
Dept. Interior, Bureau of Land Management.

WILMARTH, N. G., 1938.
The lexicon of geologic names of the United States.
U.S. Geol. Surv. Bull., 896:1-2396.

WILSON, R. W., 1949.
Preliminary report on a Torrejonian faunule from near Angel's Peak, San Juan Basin, New Mexico.
Geol. Soc. Amer. Bull., 60:1930-1931.

WILSON, R. W., 1950.
Supposed primates from the Torrejon fauna of the Nacimiento Formation.
(Abst.) Geol. Soc. Amer. Bull., 61:1515-1516.

WILSON, R. W., 1951. Preliminary survey of a Paleocene faunule from the Angel's Peak Area, New Mexico.
Kansas Univ. Mus. Nat. Hist. Publ., 5:1-11.

WILSON, R. W., 1956a.
A new multituberculate from the Paleocene Torrejon fauna of New Mexico.
Kans. Acad. Sci. Trans., 59:76-84.

WILSON, R. W., 1956b.
The condylarth genus Ellipsodon.
Kans. Univ. Mus. Nat. Hist. Publ., 9(5):105-116.

WILSON, R. W., 1956c.
Additional remains of the multituberculate genus Eucosmodon.
Kans. Univ. Mus. Nat. Hist. Publ., 9(6):117-123.

WILSON, R. W. AND F. S. SZALAY, 1972.
New paramomyid primate from middle Paleocene beds, Kutz Canyon area, San Juan Basin, New Mexico.
Amer. Mus. Nov., 2499:1-18.

WOOD, H. E., II, et al., 1941.
Nomenclature and correlation of the North American continental Tertiary.
Geol. Soc. Amer. Bull., 52:1-48.

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