MAGNETIC POLARITY STRATIGRAPHY AND FOSSIL MAMMALIA OF
THE SAN JOSE FORMATION, EOCENE, NEW MEXICO

by
Richard Allen Haskin

A Thesis Submitted to the Faculty of the
DEPARTMENT OF GEOSCIENCES
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF SCIENCE
In the Graduate College
THE UNIVERSITY OF ARIZONA

1980
STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Richard A. Naskin

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

E. H. LINDBAY
Professor of Geosciences

August 8, 1980
Date
ACKNOWLEDGMENTS

I thank Dr. Everett H. Lindsay, Dr. George G. Simpson, and Dr. Robert F. Butler for serving on my thesis committee. I am grateful to them for their guidance and support during the course of this project.

I thank my fellow students at the University of Arizona for their assistance in the field as well as for their constructive criticisms concerning this study. I thank Lou Taylor and Yuki Tomida for their help in preparing and measuring the paleomagnetic samples. I thank Lou Taylor, Yuki Tomida, Larry Flynn, and Bob McCord for their time spent prospecting for and collecting fossils in the San José and for their endurance in the collection of matrix for screen-washing.

Special thanks to Dr. Louis L. Jacobs for introducing me to the San José Formation, for his assistance in the field, and for the discovery of "Old 99" and "101".

I also express my gratitude to the residents of Regina and Lindrith for their hospitality, generosity, and kind permission to work on their land.

Financial support for this project was provided by The State of Arizona and by The National Science Foundation, Grants DES75-13616 and EAR78-03326.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. THE SAN JUAN BASIN</td>
<td>4</td>
</tr>
<tr>
<td>3. THE SAN JOSÉ FORMATION</td>
<td>10</td>
</tr>
<tr>
<td>Previous Workers</td>
<td>11</td>
</tr>
<tr>
<td>Lithologies</td>
<td>21</td>
</tr>
<tr>
<td>Lithologic Units</td>
<td>34</td>
</tr>
<tr>
<td>Fauna</td>
<td>31</td>
</tr>
<tr>
<td>Age of the San José Formation</td>
<td>35</td>
</tr>
<tr>
<td>4. PRESENT STUDY</td>
<td>38</td>
</tr>
<tr>
<td>The San José Composite Section</td>
<td>38</td>
</tr>
<tr>
<td>Stratigraphic Correlation of Sections</td>
<td>40</td>
</tr>
<tr>
<td>Fossil Localities</td>
<td>44</td>
</tr>
<tr>
<td>Magnetic-polarity Stratigraphy</td>
<td>48</td>
</tr>
<tr>
<td>Preparation and Measurement</td>
<td>49</td>
</tr>
<tr>
<td>Magnetic Properties and Polarity Determinations</td>
<td>50</td>
</tr>
<tr>
<td>Results</td>
<td>54</td>
</tr>
<tr>
<td>Correlation of the San José Section to the Magnetic-polarity Time Scale</td>
<td>57</td>
</tr>
<tr>
<td>5. DISCUSSION AND CONCLUSION</td>
<td>63</td>
</tr>
<tr>
<td>REFERENCES CITED</td>
<td>68</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Regional map of the San Juan Basin</td>
<td>5</td>
</tr>
<tr>
<td>2.</td>
<td>Upper Cretaceous to lower Eocene terrestrial formations of the San Juan Basin</td>
<td>7</td>
</tr>
<tr>
<td>3.</td>
<td>Map of the type region of the San José Formation</td>
<td>9</td>
</tr>
<tr>
<td>4.</td>
<td>Generalized correlation of Simpson's sections</td>
<td>18</td>
</tr>
<tr>
<td>5.</td>
<td>Lithologic units and topographic profile of the type region of the San José Formation</td>
<td>25</td>
</tr>
<tr>
<td>6.</td>
<td>Map of the study area</td>
<td>39</td>
</tr>
<tr>
<td>7.</td>
<td>Stratigraphic correlation of lithologic sections</td>
<td>41</td>
</tr>
<tr>
<td>8.</td>
<td>San José composite stratigraphic section and related UALP fossil localities</td>
<td>45</td>
</tr>
<tr>
<td>9.</td>
<td>Site mean directions after AF demagnetization to 150-250 oersteds</td>
<td>53</td>
</tr>
<tr>
<td>10.</td>
<td>Magnetic-polarity zonation of lithologic sections and the resulting composite magnetic section</td>
<td>55</td>
</tr>
<tr>
<td>11.</td>
<td>Correlation of the San Juan Basin Torrejonian and the Bighorn Basin Tiffanian, Clarkforkian, and Wasatchian to the magnetic-polarity time scale</td>
<td>59</td>
</tr>
<tr>
<td>12.</td>
<td>Correlation of the San José composite magnetic section to the magnetic-polarity time scale</td>
<td>61</td>
</tr>
<tr>
<td>13.</td>
<td>Generalized stratigraphic relationship of the Almagre and Largo facies</td>
<td>64</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table | Page
--- | ---
I. Faunal list of mammalian genera in the UALP San José collection | 46
ABSTRACT

A stratigraphic and temporal framework for the type region of the early Eocene San José Formation (Wasatchian) is presented. The biostratigraphy of the region is determined by correlating fossil vertebrate localities with a composite stratigraphic section. The magnetic-polarity stratigraphy of the region is established and the resulting composite magnetic-polarity column is correlated with the magnetic-polarity time scale.

The stratigraphic relationships of four lithologic sections (Arroyo Blanco, Simpson's Section 2, Lindrith Road, Regina Rincon) reveal that strata of the Largo facies occur at progressively higher horizons from north to south. The Largo facies interfingers with the Almagre facies, indicating they were contemporaneous in part. Although the diversity and abundance of taxa differ between the Almagre and Largo facies, fossil occurrences throughout the composite stratigraphic section suggest that the overall fauna was homogeneous at the generic level. The names Almagre and Largo are retained for lithologic facies and the corresponding faunal facies. Usage of these names for chronologically mutually exclusive local faunas is abandoned.
Magnetic-polarity zonations of the four lithologic sections are also compared. The San José composite magnetic-polarity column correlates with marine magnetic anomaly 24 and the uppermost part of the long reversed polarity interval immediately preceding anomaly 24.
CHAPTER 1

INTRODUCTION

The San José Formation contains the southernmost early Eocene fossil mammalian fauna in western North America. Study of this fauna is important to vertebrate paleontologists because its composition is different in many respects from similar aged faunas known from Wyoming and Colorado. This fauna is also important to the study of early Eocene mammals in general because many types for genera and species of early Eocene mammals were collected and described from the San José Formation by E. D. Cope, who first collected there in 1874. San José mammalian fossils are relatively abundant, but their collection and study have been sporadic over the last century.

The San José Formation is the youngest recognized formation within the San Juan Basin of New Mexico. The strata are entirely terrestrial and sedimentary in origin and three major lithologic facies are present within the type region of the San José. Two of these facies, the Almagre and Largo clay facies, are rich in vertebrate fossils. However, there appear to be differences in fossil abundance and diversity between these two facies and their temporal relationship is not well understood.
It has never been questioned that the fossil vertebrate assemblage from the Almagre and Largo facies is assignable to the early Eocene Wasatchian North American Land Mammal Age. However, there is no precise biostratigraphic or temporal framework within or between the two facies. This is partly because the original collection by Cope lacked stratigraphic resolution and partly because subsequent collections have been incompletely studied and published. Based on early Eocene faunas from Wyoming, the Wasatchian Land Mammal Age has been divided into three "sub-ages". However, because the San José fauna is different in composition from the Wyoming faunas, placement of the San José Formation within the Wasatchian remains nebulous.

The purpose of this study is to determine the magnetic-polarity stratigraphy of the type region of the San José Formation and to trace fossil localities within the type region into a composite magnetic-polarity sequence which can then be correlated to the magnetic-polarity time scale. This will permit more precise correlation of fossil remains within the formation and also provide a chronologic comparison with Wasatchian faunas in Wyoming. This study is an initial step in a more comprehensive study of the faunas and age of the San José Formation.
In the following discussion I: 1) characterize the general geology of the San Juan Basin, 2) review previous geologic and paleontologic study in the San José Formation, 3) characterize the lithologies, lithologic facies, and fauna of the San José Formation, 4) correlate important fossil localities within the San José Formation into a composite stratigraphic section, 5) present paleomagnetic techniques and resulting data for a composite magnetic section, and 6) suggest a correlation of the San José composite magnetic section to the magnetic-polarity time scale.
CHAPTER 2

THE SAN JUAN BASIN

The San Juan Basin is a large structural basin situated along the eastern margin of the Colorado Plateaus physiographic province (Baltz, 1967, p. 2). It occupies much of the northwestern corner of New Mexico and also extends into southwestern Colorado and relatively small areas of Arizona and Utah (Fig. 1). The basin is bounded to the north by the San Juan Mountains, to the west by the Chuska Mountains, to the east by San Pedro Mountain and Nacimiento Mountain, and to the southeast by the San Mateo Mountains. The east-west width of the basin is about 135 miles, and the north-south length is about 180 miles (Baltz, 1967, p. 59).

Rocks in the east-central part of the basin range in age from Precambrian granite and metamorphic rocks to Quaternary gravels and stream alluvium. Virtually all rocks younger than Precambrian are sedimentary in origin, with the exception of a swarm of undated lamprophyre dikes (Baltz, 1967, p. 57-58). Thick sequences of Paleozoic and Mesozoic marine and terrestrial sediments overlie the Precambrian rocks. The youngest marine strata belong to the
Figure 1. Regional map of the San Juan Basin.
late Cretaceous Pictured Cliffs Sandstone. This formation is in turn overlain by a sequence of late Cretaceous to early Eocene terrestrial sediments (Fig. 2).

Much of the previous geologic investigation in this area has dealt with the economic value of the Cretaceous terrestrial strata which are rich in coal, oil, and natural gas. Most of the geologic mapping and exploration of the Paleocene and early Eocene deposits has been incidental to these studies. The late Cretaceous strata are also of interest to vertebrate paleontologists because they contain abundant dinosaur remains, as well as remains of early mammals. Fossils of Cretaceous mammals are, however, quite scarce. The Nacimiento Formation contains the reference faunas for the early Paleocene Puercan and middle Paleocene Torrejonian North American Land Mammal Ages. The San José Formation contains the reference fauna for the late Paleocene Tiffanian North American Land Mammal Age and has yielded many types for genera and species of early Eocene mammals.

The late Paleocene strata of the San José Formation were tentatively assigned to the formation by Simpson (1948b), and they probably do not belong in the formation. This study concentrates on the type region of the San José Formation, which is early Eocene in age. This type region can be approximately defined by a "rectangle" with
Figure 2. Upper Cretaceous to lower Eocene terrestrial formations of the San Juan Basin.
Cañoncito de las Yeguas to the north, the margin of the San Juan Basin to the east, the town of Cuba to the south, and the town of Lindrith to the west (Fig. 3).

The continental divide passes through the study area approximately with a north-south orientation (Fig. 3). West of the continental divide, Oso and Cavilan Arroyos join the streams and arroyos at the head of Canyon Largo which, in turn, drains to the north and west as a tributary of the San Juan River. Streams and arroyos east of the continental divide and north of the town of Regina (mainly Blanco and Almagre Arroyos) drain north and east as tributaries of Rio Gallina which enters into the Chama River, a major tributary of the Rio Grande. Streams east of the continental divide and south of Regina drain into San José Creek which flows south into the Puerco River which joins the Rio Grande about 120 miles south of Cuba.
Figure 3. Map of the type region of the San José Formation.

Map is based on Simpson's description (1948b, p. 281).
Figure 3. Map of the type region of the San José Formation.
CHAPTER 3

THE SAN JOSE FORMATION

The San José Formation is the youngest Tertiary formation within the San Juan Basin and lies northeast of the basin's geographic center (Fig. 1). The San José Formation was named by Simpson (1948b) for the San José Valley in northwestern Sandoval County, New Mexico. San José Creek intermittently flows through this valley (Fig. 3). The San José Formation includes all of the early Eocene strata within the San Juan Basin, plus the late Paleocene "Tiffany" beds of Granger (1917) which lie in the northern part of the basin in Colorado.

San José strata are entirely sedimentary in origin resulting from terrestrial fluvial aggradation. The formation is exposed within an area of approximately 3,250 square miles and reaches a total thickness of at least 2,000 feet (Simpson, 1948b, p. 258). Exposures vary greatly in thickness due to differential erosion, and vary in lithologic continuity due to limits of stratigraphic exposure. As a result, no single exposure provides a complete lithologic section within the formation. For this reason, the San José Formation is defined by a type region rather than by a type section. The majority of exposures are well
under 1,000 feet in thickness, and the thickness of an "average" exposure is around 500 feet. Lithologies, facies, fauna, and age of the San José Formation will be discussed in detail following the next section on previous workers.

Previous Workers

This study is centered within the type region of the San José Formation because virtually all previous fossil collecting in the formation has been concentrated there. The San José Formation has been studied intermittently by many geologists and paleontologists over the last century. The history of investigation has been summarized by Simpson (1948b, 1950, 1951), Baltz (1967), and Lucas (1977), and will be briefly reviewed here.

The first trained geologist to see the beds of the San José Formation was J. S. Newberry, who travelled across the San Juan Basin from the San Juan River to San Pedro Mountain in 1859 with the Macomb expedition (Simpson, 1950, p. 85). Newberry tentatively assigned the entire Paleocene-Eocene section of the San Juan Basin to the Cretaceous.

Vertebrate fossils were first "discovered" within the San José Formation by E. D. Cope on September 7, 1874 while he was working for the Wheeler Survey (Simpson, 1951, p. 12). Cope recognized a faunal similarity to fossils from the early Eocene Wasatch Formation in southwestern Wyoming and assigned these beds to that formation. Thus, Cope was
the first to recognize the early Eocene age of these strata, and he considered this discovery "the most important find in geology I ever made" (Osborn, 1931, p. 201). Cope collected most of his fossils in two major "horseshoes" which Simpson (1948b, p. 262) has identified as arroyos Blanco and Almagre (Fig. 3). Cope briefly prospected the beds west of the continental divide near the head of Gavilan Arroyo, but found few fossils in these exposures. Cope continued to work these early Eocene beds for approximately two months.

Many of Cope's specimens became types for early Eocene genera and species (Cope, 1874, 1875a,b, 1884). Cope's largest report on these specimens was made for the Wheeler Survey (Cope, 1877) in which he described and illustrated his collection. Cope also mentions the fauna in many shorter publications (Cope, 1875c, 1881a,b, 1882, 1876 a,b,c,d,e). As was common practice at the time, Cope did not record precise stratigraphic and locality data which has led to confusion regarding the provenience of many of his type specimens. Cope never returned to the San Juan Basin after this expedition. (For details of Cope's discovery of these early Eocene strata see Simpson, 1951).

David Baldwin, a native of New Mexico, collected Eocene fossils in this region for Cope's rival, O. C. Marsh, from 1876 to 1880 (see Simons, 1963). Apparently dissatisfied in his association with Marsh, Baldwin shifted his
allegiance and went to work for Cope in 1880. Baldwin collected mainly west of the continental divide within the Largo drainage. These beds are stratigraphically higher and of different facies than the beds east of the divide from which the majority of Cope's original collection was made. Baldwin's greatest discovery, however, was of mammals in Cope's "Puerco" further south. These specimens were the first known mammals of the continental Paleocene (Simons, 1963, p. 1). Baldwin continued collecting mainly in these beds until 1888. Baldwin also constructed the first "geologic map" of the San Juan Basin by cutting out pieces of paper representing successive lithologic units and placing them on top of each other (Simons, 1963, Fig. 1). Some of the material collected by Baldwin for Marsh was discussed by Thorpe (1934).

In 1896 J. L. Wortman led an American Museum of Natural History expedition to revisit Cope's San Juan Basin localities in the exposures along the east rim of the basin. Wortman found few fossils and a small collection was made (see Osborn, 1898). Matthew (1899, 1909) published faunal lists of the Tertiary mammals of western North America which included species from the early Eocene of New Mexico.

The next major representative collection of San José fossils was made by Walter Granger for the American Museum of Natural History in 1912 and 1913. Granger
collected in the same general areas east of the continental divide where Cope had worked and apparently did not collect in the exposures northwest of the divide near Gavilan and Oso Arroyos where Baldwin had collected (Simpson, 1948b, p. 264). Granger (1914, p. 205) referred to these San José exposures as the "Wasatch beds of northwestern New Mexico", and noticed that the overall faunal content from this area was different from that of the "Bighorn Wasatch" (the Willwood Formation, Bighorn Basin, Wyoming, of present terminology). Because of this faunal difference, Granger (1914) proposed that the San José should have "horizon" names (my quotations) distinct from the Gray Bull, Lysite, and Lost Cabin of Wyoming. Granger also noticed a faunal difference within the San José between the oldest and youngest exposures, and he named two "horizons". The upper third of the section was characterized by the presence of the condylarth genus *Meniscotherium* and Granger named this upper division the Largo beds, after the Largo drainage on the west side of the continental divide. The lower two-thirds of the section did not contain *Meniscotherium*, and Granger named this lower division the Almagre beds, after Almagre Arroyo on the east side of the continental divide. Granger placed the boundary between these two divisions, as indicated by the first appearance of *Meniscotherium*, "about 50 feet above the low divide which separates the headwaters
of Largo Canon and the southwest branch of Almagre Arroyo, about 5 miles northwest of Ojo San José" (Granger, 1914, p. 206). This low divide is in the northeast ¼ of section 8, T. 23 N., R. 1 W., Regina, New Mexico 7½' quadrangle (Fig. 3). Thus, Granger referred the names Largo and Almagre to strata, but the faunal difference between these strata was foremost in his mind. Subsequent workers, therefore, refer the names Largo and Almagre to different faunas as well.

Granger suggested that the Largo fauna resembled the Lost Cabin of Wyoming, in general, because at that time the only other specimen of *Meniscotherium* was from the Lost Cabin beds of the Wind River Basin. (*Meniscotherium* is now known to have ranged from late Paleocene through the early Eocene, see Gazin, 1965). Granger suggested that the Almagre fauna has characters of both the Lysite and Gray Bull of Wyoming. Granger (1915), Matthew (1915a,b,c, 1918), and Sinclair (1914) published a thorough review of the "lower Wasatch and Wind River faunas" which included Granger's San José collection.

After Granger's work, fossil collecting in the San José Formation came to a virtual halt for more than 40 years. C. L. Gazin, with a party from the United States National Museum, made a small collection in Almagre Arroyo (see Gazin, 1937). Van Houten (1945) reviewed all of the
late Paleocene and early Eocene mammalian faunas of North
America and gave faunal lists for the Largo and Almagre
faunas. During this lull in paleontologic activity, a
great deal of geologic reconnaissance was done in the San
Juan Basin by members of the United States Geological Sur­
vey (USGS). Strata now recognized as belonging to the San
José Formation were then mapped as part of the Wasatch
Formation, although the various workers did not always in­
clude the same strata when mapping the limits of their
"Wasatch" (see Baltz, 1967, p. 44-45). Some of the more
important studies were done by Reeside (1924), who mapped
the base of the formation in the north and west; by Renick
(1931), who studied the potential of the formation as an
aquifer; by Dane (1936, 1946), who mapped the base of the
formation along its southern and eastern margins; and
Northrop and Wood (1946), who also mapped along the eastern
margin of the formation.

The next major study of the area by a paleontologist
was initiated in 1946 by G. G. Simpson for the American Mu­
seum of Natural History and continued through the early
1950's. Simpson formally named the San José Formation in
1948 (see Simpson, 1948b) and in several publications
(1948a,b, 1950, 1951) reviewed previous studies in the area
and gave new insight into the stratigraphy and fauna of the
formation. Simpson collected further in the areas covered
by previous workers and included these exposures in his type region for the formation.

Simpson did not formally subdivide the San José Formation, but did distinguish three major facies within the type region; a major sandstone facies and two clay facies. The two clay facies correspond with Granger's Almagre and Largo beds and Simpson referred to them as the "Almagre" and "Largo" facies (Simpson, 1948b, p. 368). Simpson suggested (1948b, p. 275) that the Almagre and Largo should be considered "as names of local faunas (or faunal facies) and not as rock units, although .... the names can also conveniently be applied to sedimentary facies". Simpson (1948b, p. 370-374) presented three detailed lithologic sections to illustrate the characteristic lithologies within the two clay facies. A generalized correlation of these sections, based on Simpson's descriptions, is shown in Figure 4. This figure is not intended to show the detail of the lithologies, but only their relative stratigraphic position as discerned by Simpson. Section 1 is entirely within the Largo facies near the head of Oso Arroyo. Section 2 is essentially the type locality of Granger's Almagre and Largo. Within Section 2, Simpson (1948b, p. 372) designated the first red band (unit "q") as the Almagre-Largo facies boundary. Section 3 is on the south rim of Arroyo Blanco and entirely within the Almagre facies (Fig. 3).
Figure 4. Generalized correlation of Simpson's sections.

Sections are drawn based on Simpson's descriptions (1948b, p. 370-374). Unit "q" in section 2 is taken by Simpson (1948b, p. 372) as the base of the Largo facies.
Figure 4. Generalized correlation of Simpson's sections.
Simpson recognized evidence, also noted by Granger (1914), of visible age difference between the lowest and highest fossil occurrences in the formation. Simpson suggested (1948b, p. 380-381) that the differences in age and fauna correspond broadly with the two clay facies, and noted that the "most obvious difference, and that which induced Granger to separate the two, is the absence of Meniscotherium in the Almagre facies while in the Largo facies it is usually the most abundant fossil". Simpson (1951, p. 16) amended this statement by adding that, although Meniscotherium is a guide fossil for the Largo, it is not entirely confined to that facies. Simpson briefly discussed "sub-age" designation for the Almagre and Largo within the Wasatchian and concluded that the Largo fauna is probably nearer Lysite (middle Wasatchian), or even Gray Bull (early Wasatchian), than Lost Cabin (late Wasatchian), and that the Almagre fauna is probably nearer Gray Bull (Simpson, 1948b, p. 382).

Fossils recovered by Simpson during his expeditions in the San José Formation are described (in part) in papers on a new species of apatemyid (Simpson, 1954) and a new species of phenacolemurid (Simpson, 1955). Simpson briefly mentions a quarry containing 14 nearly complete skeletons of Coryphodon in two publications (Simpson, 1951, 1953) and
describes his quest for new *Meniscotherium* material in a
general paper describing his 1947 field season (Simpson,
1948a).

Between Simpson's study and the present study, no
major fossil collections have been made in the San José
Formation. The Departments of Anthropology and Geology at
The University of New Mexico have collected in the San José
over the past few years, and Lucas (1977) reports a collec­
tion of over 200 identified specimens and casts of San José
animals in the Department of Geology at that institution.
Many museum specimens from existing collections of San José
fossils have been studied by the following experts investi­
gating specific groups of animals: Kitts (1956),
*Hyracotherium*; Gazin (1965, 1968), *Meniscotherium* and
*Hyopsodus*; Krishtalka (1976), adapisoricid insectivores;
and Gingerich and Simons (1977), adapid primates. Thus,
descriptions, discussions, and faunal lists of San José
vertebrates are scattered throughout the literature, in­
cluding the publications of the above authors, as well as
those mentioned previously by Cope, Granger, Matthew,
Sinclair, Simpson, Van Houten, and Thorpe. A review of the
entire fauna seems to be warranted.

E. H. Baltz made a geologic study in 1959-1960 that
included the east-central San Juan Basin as part of a
ground-water investigation by the USGS. He mapped and
named four lithologic members within the San José Formation. The Regina Member contains the Almagre facies of Simpson and the lower part of Simpson's Largo facies. The Tapicitos Member corresponds to the upper part of Simpson's Largo facies. The relationships of these members and facies will be discussed in detail in a following section.

Regarding the San José strata in southwestern Colorado, J. W. Gidley of the United States National Museum made a small collection of mammals near Ignacio, Colorado, in 1909 (see Wegemann, 1917). Gidley correctly suggested that these specimens were intermediate in age between Torrejonian (middle Paleocene) and Wasatchian. In 1916, Granger worked these same beds and found a rich concentration of small mammals called the "Mason Pocket" (see Granger, 1917). This is now known as the Tiffany Local Fauna and is the reference fauna for the Tiffanian North America Land Mammal Age (see Simpson, 1935a,b,c).

**Lithologies**

The lithologies, lithologic facies, fauna, and age of the San José Formation are discussed by Simpson (1948b), Baltz (1967), and Lucas (1977) as well as by other previous workers. The following characterization of these features is based on these previous descriptions, as well as on my own field observations.
The San José Formation consists of lenticular banded clays, sandstones, and conglomerates which characterize lithology and fabric of fluvial deposition. The banded clays appear to be quite uniform on the weathered surface, but upon inspection of unweathered surfaces they are locally complex (see Simpson, 1948b, p. 364). The grain sizes of the clays are highly gradational and most of them are quite silty. I will, however, continue to use the term clays as a general reference to these fine-grained banded deposits. In color, the majority of bands are buff, yellow, tan, and gray. Bands of purple and lavender are common, and red, bluish, and green bands are present, but less common. Pale red to maroon bands are most common in the upper part of the formation. These bands are often highly mottled. The clay bands are broadly lenticular and, although not continuous laterally, some are quite extensive and persist over several miles. The clays are replaced laterally by other clays and often by channel sands. These deposits probably represent aggradation on a rather broad flood plain. Carbonized plant remains occur in a few thin-bedded or laminated clays. These clays probably represent temporary lakes or puddles on the floodplain. These carbonaceous strata are localized and rare and are not typical of the formation.

The sandstones of the San José Formation are also lenticular and two general modes of sandstone deposition
can be distinguished. Mode 1 is represented by broadly lenticular sandstones which often persist laterally for several miles. These sands probably represent a single, major flooding event over a large area. These sands are usually between 5-50 feet thick. They are often moderately to poorly sorted, medium to coarse-grained, and appear massive from a distance, but are highly cross-bedded upon close inspection. They are often conglomeratic locally and are usually resistant, forming conspicuous ledges and cliffs. They are usually dark in color and weather to buff, yellow, and brown.

Mode 2 is represented by more localized lenticular sandstones which are less persistent in cross-section, often on the order of tens of feet up to perhaps a quarter of a mile. These sands were probably deposited in well-defined, local channels. These sandstones are usually less than 25 feet thick. They are usually "soft", moderately to well sorted, fine to coarse grained (often argillaceous), and pale in color, often white or gray mottled with yellow. The most persistent of these Mode 2 "channel type" sandstones intergrade in character with the more broadly lenticular "flood type" sandstones of Mode 1 and, therefore, the "flood type" and "channel type" sandstones are sharply distinguishable only where more typically developed.
Lithologic Units

Three major lithologic facies of the San José Formation are present in its type region. These facies were first described by Simpson (1948b). A thick sandstone sequence occurs in the northern part of the type region and is best developed in Cañoncito de las Yeguas. (This canyon is referred to as Yegua Canyon by most previous authors. It is, however, presently named Cañoncito de las Yeguas on the Llaves quadrangle topographic map and on road signs erected in the area by the U. S. Forest Service.)

The sandstones of this facies are mostly of the "massive", coarse-grained, "flood type" of Mode 1 and are often conglomeratic. Simpson did not give a specific name to this facies, but referred to it as "the major sandstone facies of Yegua Canyon" (Simpson, 1948b, p. 367). I will refer to this facies as the "Yegua" facies (Fig. 5a). A distinctive lower unit of the Yegua sandstone facies extends under the formation to the south and is recognized as the basal unit of the formation throughout the type region (Simpson, 1948b, p. 367; Baltz, 1967, p. 46). Baltz (1967) has mapped this basal sandstone and named it the Cuba Mesa Member of the San José Formation (Fig. 5b), after Cuba Mesa which is in the southern part of the region near the town of Cuba (Fig. 5c). The Cuba Mesa Member is 782 feet thick at the type section (Baltz, 1967, p. 46), but locally only as
Figure 5. Lithologic units and topographic profile of the type region of the San José Formation.

(a) Lithologic facies (Simpson, 1948b, and this study); (b) Lithologic members of Baltz (1967); (c) Generalized topographic profile along the continental divide looking from the east toward the west.
Figure 5. Lithologic units and topographic profile of the type region of the San José Formation.
much as 50-75 feet thick in some areas. Baltz mapped the upper part of the Yegua sandstone facies, typical of the Cañoncito de las Yeguas area, and named it the Llaves Member of the San José Formation (Fig. 5b), after the town of Llaves which is about 1¼ miles southwest of these exposures. This member reaches a maximum thickness of 1,300 feet (Baltz, 1967, p. 51) in the western part of the region.

At the head of Cañoncito de las Yeguas, the Cuba Mesa Member is 335 feet thick and the overlying Llaves Member is almost 700 feet thick (Baltz, 1967, p. 50) yielding a total thickness for the Yegua facies in this area of approximately 1,000 feet. Simpson (1948b, p. 367) had estimated this thickness to be nearly 1,000 feet. The upper part of the Yeguas facies (Llaves Member) intertongues with and grades into the two major clay facies to the south and west (Fig. 5a).

The second major facies of the San José Formation is a drab-colored clay facies which crops out over most of the southern part of the type region. The clays of this facies are highly variegated and pale in color. Yellowish to tan colored bands predominate. Purple to lavender bands are common, while blues and greens are present, but less common. Red bands are very rare in the lower part of the facies and are more common, but still rare overall, in its upper part. This facies also contains numerous interbedded sandstones of
the soft, fine-grained, channel type and a few sandstones of the resistant, coarse-grained, cliff-forming type. This facies overlies the basal sandstone unit of the Yegua facies and grades to the north into the upper part of the Yegua facies (Fig. 5a). This predominantly clay facies was named the "Almagre facies" by Simpson (1948b, p. 368). The Almagre facies is best exposed on the south rim of Arroyo Blanco, in the middle of Almagre Arroyo, and east of the continental divide low in the Badland Hills northwest, west, and southwest of the town of Regina (Fig. 5c).

The third major facies is also a predominantly clay facies much like the Almagre facies. However, most of its clays are red to bright red in color and are commonly expressed as narrow bands separated by wider bands of white to gray sandstone. Some pale, variegated clays of the "Almagre" type are present locally, but are rare. This facies forms the upper part of the formation in those areas where it has not been eroded away. In general, it overlies and intergrades with the Almagre where they are in contact (Fig. 5a). This facies was named the "Largo facies" by Simpson (1948b, p. 369). The interdigitation of the Almagre and Largo facies is most easily observed on the north and west rims of Arroyo Blanco. The Largo facies also inter­tongues and intergrades with the upper part of the Yegua facies to the north (Fig. 5a). The Largo is best developed
west of the continental divide in the northwestern part of the region near the heads of Gavilan and Oso Arroyos (Fig. 5c). It is also exposed, but less distinct, on the west side of the divide in the uppermost part of the Badland Hills at the head of Largo Canyon.

The Almagre and Largo facies have never been separately mapped. Although easily distinguishable over wide areas where they are typically developed, no sharp, persistent, mappable lithologic division can be made where they intergrade (see Simpson, 1948b, p. 369; Baltz, 1967, p. 49). For this reason, Baltz (1967) has somewhat arbitrarily subdivided the two facies into two mappable lithologic units. These units were mapped and named the Regina Member of the San José Formation, for exposures near the town of Regina, and the Tapicitos Member of the San José Formation for exposures in the upper drainage of Tapicitos Creek and near Tapicitos Post Office (Baltz, 1967, p. 48-52). As defined by Baltz (1967, p. 49), the Regina Member includes the Almagre facies and the red clays and sandstones along the continental divide which are the lower part of the overlying Largo facies. The Tapicitos Member is equivalent to the upper part of the Largo facies in the northwestern part of the region (Fig. 5b). Baltz (1967, p. 49 and 51) states that a persistent unit of the Llaves Member, approximately 50-100 feet thick and consisting of sandstone and a few beds
of shale at places, extends southward and westward. This persistent sandstone unit rests on the Regina Member in much of the northern part of the region and separates it from the overlying Tapicitos Member. Thus, the Tapicitos Member comprises the beds of the Largo facies above the persistent sandstone unit of the Llaves Member, and the Regina Member includes the Almagre facies and all of the beds of the Largo facies below the persistent sandstone (Fig. 5b). As stated by Baltz (1967, p. 48 and 53), the maximum thicknesses of the Regina and Tapicitos Members are 575 feet and 500 feet respectively. Thus, the combined thickness of these two members is approximately 1,100 feet.

A composite lithologic section developed for the present study (discussed in Chapter 4) is approximately 900 feet thick. That part of the section which is essentially within the Almagre facies suggests that this facies is at least 750 feet thick overall. Simpson (1948b, p. 370-371) measured a section entirely within the Largo facies of 250 feet. Baltz (1967, p. 52) suggests that there is at least 120 feet of Largo strata above the top of Simpson's section. Indeed, I have measured a section in the same general area (near the head of Oso Arroyo) of 376 feet. Thus, the combined thickness of the Almagre and Largo facies as measured in this study is approximately 1,100 feet, which is in agreement with the combined thickness of the Regina
and Tapicitos Members. Therefore, the composite thickness for the San José Formation is 1,100 feet, plus 800 feet for the Cuba Mesa Member, or approximately 1,900 feet. This is, however, a composite thickness based on addition of maximum thicknesses of units which actually vary in thickness throughout the area. Thus, no single exposure reaches such a thickness.

Two other unmapped lithologic units exist within the San José Formation outside of the type region. To the northwest, in the general vicinity of the town of Gobernador, is a unit that is mainly clays and silts very similar in lithology to the Almagre facies. This area has never been studied in detail, but Baltz (1967, p. 56) suggests that it is stratigraphically equivalent to the lower part of the Llaves Member and to the Regina Member.

Farther to the northwest, in Colorado, are the "Tiffany" beds of Granger (1917). These beds are also pale, variegated clays and interbedded sandstones. The stratigraphic relationship of these beds to the type region of the San José Formation has never been adequately documented and they were only tentatively assigned to the San José Formation by Simpson (1948b, p. 383) with the understanding that they probably do not belong in the formation.

In summary, three major lithologic facies are present within the type region of the San José Formation:
the Yegua (sandstone) facies, the Almagre (variegated clay) facies, and the Largo (red clay) facies. These facies have been subdivided and mapped as four members: Cuba Mesa, Llaves, Regina, and Tapicitos. The Cuba Mesa and Llaves Members correspond to the lower and upper parts of the Yegua facies, respectively. The Regina Member includes the Almagre facies, plus the lower beds of the Largo facies, and the Tapicitos Member includes the remaining upper part of the Largo facies.

The Almagre and Largo facies are bodies of rock, each of which is an internally homogeneous, genetic, lithologic unit. The persistent sandstone boundary between the Regina and Tapicitos Members "arbitrarily" cuts across facies boundaries. Thus, the Regina Member contains rocks of both the Almagre and Largo facies and is, therefore, not an internally homogeneous, genetic, lithologic unit. The Regina and Tapicitos members are contrary to some stratigrapher's concept of what should comprise a "member". There is no evidence that these members are appreciably different in age, character, or origin.

**Fauna**

Fossil vertebrates are encountered throughout the type region of the San José Formation. They are, however, quite rare within the major sandstone facies and I have made no effort to prospect the "massive" sandstones. However,
small "pockets" of fossils are often encountered within the white, argillaceous, channel sandstones of the Almagre facies. The vast majority of fossils are found on the surface of, and within, the clays of both the Almagre and Largo facies.

Fossils are usually isolated in nature, consisting of individual teeth and/or bone fragments. Jaws and jaw fragments are relatively abundant, but complete, articulated specimens are rare. Fossils are most commonly found weathered out and accumulated at the base of hills as lag, and the producing layer is often hard to find. Fossil localities are known throughout the area, both vertically and horizontally, but they appear to occur almost at random and no extensive producing horizon has been found.

Concentrations of bones sufficient enough to warrant quarrying are rare. Simpson (1948b, p. 380) reports three such quarries, two (#58 and #88) within the Almagre facies, and one (#150) in the Largo facies. Locality #150 contained, almost exclusively, remains of the condylarth genus Meniscotherium. This is the only locality in the Largo facies, to my knowledge, that has any noteworthy concentration of bone. Simpson's localities #58 and #88 contained remains of many small mammals. Simpson also reported (1951, p. 20; 1953, p. 14-15 and 37) a quarry within the Almagre facies which contained the remains of a "family" of
pantodons of the genus Coryphodon. This quarry yielded the remains of 14 individuals, including adults and juveniles. These 14 individuals had been preserved and fossilized all absolutely complete and articulated. However, one side of the accumulation had been exposed by erosion and the hind parts of a couple of skeletons had been washed away (Simpson, 1980, pers. comm.). During the summer field season of 1977, Dr. Louis L. Jacobs, then a member of The University of Arizona Laboratory of Paleontology (UALP) field crew, discovered three localities within the Almagre facies suitable for screen-washing. These localities have yielded large numbers of small vertebrates.

Fossils known from the type region of the San José Formation include gastropods, fishes (gar and reworked Cretaceous sharks), lizards, crocodiles, turtles, a bird (Diatryma, first described from here by Cope, 1876b), and a large number of mammalian species. Lucas (1977, p. 223) reports that 31 nonmammalian species and 71 mammalian species are known from the area.

The most common mammalian genera are the equid Hyracotherium, and the previously mentioned genera Coryphodon and Meniscotherium. The condylarth Hyopsodus is common in the screen-washing localities, as are several taxa of rodents (paramyids and sciuravids). These screen-washing localities have also yielded several specimens of
insectivores and primates, as well as the first specimens of multituberculates known from the San José Formation. It is also pertinent to note the absence of the non-equid perissodactyls which are characteristic of similar aged deposits in Wyoming.

The Almagre and Largo facies differ in their faunal content, as well as lithologically. Within the Almagre facies, gar scales, turtles, crocodiles, and Coryphodon are abundant. These vertebrates are also present in the Largo facies, but are less common. The major faunal difference between the two facies is the abundant representation of Meniscotherium in the Largo and its near absence in the Almagre. Lucas (1977, p. 224) reports that four specimens of Meniscotherium are known from the Almagre facies. The UALP crew has recovered seven specimens of Meniscotherium from the beds intertonguing or gradational between the two facies and it is difficult to know from which facies they were derived. Thus, there is a possibility that at least 11 specimens of Meniscotherium are known from the Almagre facies, while hundreds are known from the Largo. Approximately 30 genera of vertebrates are known from the Almagre facies that have not been found in the Largo, while approximately 20 genera have been reported from both facies. With the occurrence of Meniscotherium in the Almagre, no genera are restricted to the Largo facies. These differences in
fossil occurrences between the Almagre and Largo facies have led to the interchangeable usage of the names Almagre and Largo for local faunas, or faunal facies, as well as for the lithologic facies themselves.

**Age of the San José Formation**

Cope was the first scientist to discover fossils within the type region of the San José Formation. Based on faunal similarities between his collection and faunas already familiar to him from Wyoming, Cope assigned the San José strata to the early Eocene. This age assignment has been accepted by all subsequent researchers, and the assemblage is recognized as belonging to the Wasatchian North American Land Mammal Age, based on the abundant remains of genera such as *Hyracotherium*, *Coryphodon*, *Meniscotherium*, and *Hyopsodus*, as well as the presence of *Pelycodus*. However, precise correlation within the Wasatchian is still open to question.

The large diversity of perissodactyls in the Bighorn and Wind River Basins of Wyoming is the basis for recognizing a three-fold subdivision of the Wasatchian into Graybullian (early Wasatchian), Lysitean (middle Wasatchian), and Lostcabinian (late Wasatchian). The perissodactyls characteristic of these "sub-ages" are, however, not known from the San José Formation. Therefore, based on comparisons of other taxa, Granger (1914) suggested that the Largo
fauna represents Lostcabinian and the Almagre represents Graybullian and Lysitean. Van Houten (1945) emphasized that close correlations between faunas different in facies and geographic location is difficult, but, nevertheless, suggested that the Largo may be near Lysitean, and the Almagre nearer Graybullian. Simpson (1948b, p. 383) suggested that "Van Houten's opinion is likely to be nearly correct" and stated that "it is doubtful whether separation into two successive faunas can be clearly maintained". Gingerich and Simons (1977, p. 261 and 272) suggest that the San José fauna, as a whole, is Lostcabinian in age based on analysis of the evolution of adapid primates. More recent analysis of the overall fauna has also suggested to Lucas (1977, in press) that the San José Formation is Lostcabinian in age.

The present study was undertaken in hopes that a more precise biostratigraphic framework within the type region of the San José Formation, and paleomagnetic studies in both the San José and Wyoming, will lead to a more precise correlation. The initial data for the San José are reported in the next chapter of this study.

The San José Formation outside of its type region has been essentially ignored in the past. Simpson (1980, pers. comm.) spent considerable time prospecting outside the type area on the Jicarilla Apache Reservation, but the pickings there were not rich, although some specimens were
obtained. The UALP crew has briefly prospected in the clay facies of the Gobernador area in hopes that it might possibly represent the Clarkforkian North American Land Mammal Age which is unknown within the San Juan Basin. We have found specimens of Hyracotherium, Coryphodon, Phenacodus, and the tortoise Hadrianus, as well as gar scales and crocodile. These taxa suggest a Wasatchian age for these strata, and the presence of Hadrianus suggests an age of late Graybullian or younger (Savage, Waters, and Hutchinson, 1972, p. 39). The "Tiffany" beds of Granger (1917), in Colorado, are late Paleocene in age and contain the reference fauna for the Tiffanian North American Land Mammal Age.
CHAPTER 4

PRESENT STUDY

This study was initiated during the summer of 1977 by The University of Arizona Laboratory of Paleontology (UALP) and The University of Arizona Paleomagnetism Laboratory. The major aim of this study is to establish a precise temporal framework within the type region of the San José Formation. This study is centered within the type region of the formation because virtually all previous fossil collecting and geological work done in the San José has been concentrated there. This chapter consists of three major parts. First, a composite stratigraphic section within the type region of the San José is developed and fossil localities are tied into this section. Second, techniques used in obtaining paleomagnetic data are discussed. Third, the paleomagnetic data are interpreted and a magnetic-polarity sequence is established within the composite stratigraphic section.

The San José Composite Section

The San José composite section is approximately 900 feet thick. It comprises four sections designated south to north (Fig. 6): 1) the Regina Rincon section, just west
Figure 6. Map of the study area.
of Regina; 2) the Lindrith Road section, just south of where Highway 95 to Lindrith cuts through the continental divide; 3) Simpson's Section 2 (essentially Granger's type for his Almagre and Largo beds); and 4) the Arroyo Blanco section, circumscribing Arroyo Blanco. The Arroyo Blanco section consists of three partial sections which are joined by laterally continuous tracer beds. Partial section "a" is stratigraphically lower than partial section "b", which is in turn lower than partial section "c". These sections are all within Baltz's (1967) Regina Member of the San José Formation.

Stratigraphic Correlation of Sections

To establish the stratigraphic relationships of these four sections, distinctive lithologies were traced between them. However, due to the rapid horizontal variability of the sections, no single unit extends laterally from any one section to the next. Therefore, it was necessary to use a series of discontinuous tracer beds, each measured relative to the adjacent tracer, to join the sections (Fig. 7). This process involves tracing a distinctive lithologic unit within a given section to its limit, and then measuring either up or down to another distinctive unit which is then traced to its limit. This procedure is continued to the next section. Specifically, the "rust red" tracer, high in the Regina Rincon section, was
Figure 7. Stratigraphic correlation of lithologic sections (see text for discussion).
traced northward until it pinched out. A measurement of 
-143 feet was then made down to another tracer, designated 
the "cattle guard gray". The "cattle guard gray" was 
traced northward until it pinched out. A measurement of 
+100 feet was then made up to the "thin rust" tracer. This 
"stair-step" procedure was continued northward into the 
"upper purple" tracer in the Lindrith Road section. The 
same procedure was then continued to the "section red" 
tracer in the upper part of the Arroyo Blanco section. 
The net stratigraphic thickness between the "rust red", 
"upper purple", and "section red" tracers can then be com­ 
puted by summing the measurements between the successive 
tracers. In Figure 7, going from south to north, positive 
measurements are measurements made up to the next tracer, 
and negative measurements are measurements made down to the 
next tracer. The scale to the left and right in Figure 7 
is in feet with the base of the Arroyo Blanco section 
designated as 0. The horizontal axis is not to scale.

In total, 24 tracer beds were traced a distance of 
approximately 8 miles to connect the sections. The "aver­
age" distance traced along one tracer bed was about 1,000 
feet, although, in some instances it was only from one 
hillside to another, about 100 feet away. The maximum 
vertical separation between two tracers is 150 feet between 
the "deep red" and the "passionate purple". It is realized
that this method lacks precision. However, it is the only feasible method to correlate between the sections. Measurement of complete sections at each exposure containing a tracer bed would not make the correlations more reliable regarding stratigraphic placement, although interdigitation of facies would become apparent. If the sections were correlated by elevation using a sensitive altimeter the resolution could not be securely placed within a limit of about 100 feet or more, and I estimate the error in stratigraphic placement using the above method is less than 100 feet. These stratigraphic relationships will be corroborated in subsequent discussion by the fact that magnetozones are duplicated between the sections at approximately the same stratigraphic levels.

Simpson's Section 2 was subsequently tied into this framework by measuring the stratigraphic distance of his "unit q" (Simpson, 1948b, p. 372) above the "golden yellow" tracer, just north of the Lindrith Road section. The measurement between these two units was 180 feet. The resulting relationship between the Arroyo Blanco section and Simpson's Section 2 is very close to the relationship suggested by Simpson (Fig. 4). Also note in Figure 7 that the lower 350 feet of the Arroyo Blanco section are stratigraphically below the entire Regina Rincon section.
Fossil Localities

Fossil localities in the area can be tied to the above framework by tracing into the nearest marker bed. Many new localities were discovered while tracing units and were thus directly tied into this framework. Many of the localities found in years previous to 1977 remain to be tied into this framework. By combining the four stratigraphic sections and the related fossil localities, a composite section is established which places the fossil localities into a relative stratigraphic and chronologic sequence (Fig. 8).

Table I is a faunal list of mammals in the UALP collection. Localities are placed in their relative stratigraphic order with the oldest localities to the left. Localities 7745 and 7747 are very productive localities that have been screen-washed, which accounts for their greater diversity of small mammals. Locality 7746 is a small quarry which has produced several Coryphodon bones, and, upon washing of the matrix, has yielded several isolated small mammal teeth. The majority of other localities yielded isolated specimens.

As one might expect, Hyracotherium and Coryphodon are the most common genera and were found at almost all localities. Meniscotherium first occurs at locality 7860 and is represented at four higher localities. These five
Figure 8. San José composite stratigraphic section and related UALP fossil localities.
TABLE I. Faunal list of mammalian genera in the UALP San José collection.

Localities are placed in their relative stratigraphic order from left to right, oldest to youngest.

<table>
<thead>
<tr>
<th>Genus</th>
<th>UALP Locality Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>cf. Parectypodus</td>
<td>x</td>
</tr>
<tr>
<td>Peradectes</td>
<td>x</td>
</tr>
<tr>
<td>Oxyaena</td>
<td>x</td>
</tr>
<tr>
<td>Ambloctonus</td>
<td>x</td>
</tr>
<tr>
<td>Didymictis</td>
<td>x</td>
</tr>
<tr>
<td>Esthonyx</td>
<td>x</td>
</tr>
<tr>
<td>Coryphodon</td>
<td>x  x  x  x  x  x  x  x  x  x</td>
</tr>
<tr>
<td>Palaeictops</td>
<td></td>
</tr>
<tr>
<td>Scenopagus</td>
<td></td>
</tr>
<tr>
<td>Macrocranion</td>
<td>x  x</td>
</tr>
<tr>
<td>Leptacodon</td>
<td>x</td>
</tr>
<tr>
<td>Nyctitherium</td>
<td>x</td>
</tr>
<tr>
<td>Apatemys</td>
<td>x</td>
</tr>
</tbody>
</table>
TABLE I, Continued

<table>
<thead>
<tr>
<th>Genus</th>
<th>UALP Locality Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prodiacodon</td>
<td>x x</td>
</tr>
<tr>
<td>Phenacolemur</td>
<td>x</td>
</tr>
<tr>
<td>Microsyoops</td>
<td>x</td>
</tr>
<tr>
<td>Niptomomys</td>
<td>x</td>
</tr>
<tr>
<td>Paramys</td>
<td>x x</td>
</tr>
<tr>
<td>cf. Sciuravus</td>
<td>x x</td>
</tr>
<tr>
<td>Pelycodus</td>
<td>x</td>
</tr>
<tr>
<td>Copelemur</td>
<td>x x</td>
</tr>
<tr>
<td>Chriacus</td>
<td>x x</td>
</tr>
<tr>
<td>Hyopsodus</td>
<td>x x</td>
</tr>
<tr>
<td>Phenacodus</td>
<td>x</td>
</tr>
<tr>
<td>Meniscotherium</td>
<td>x x x x x x x x x x</td>
</tr>
<tr>
<td>Hyracotherium</td>
<td>x x</td>
</tr>
<tr>
<td>Diacodexis</td>
<td>x</td>
</tr>
</tbody>
</table>
localities are all high in the section in the Regina area. These occurrences correspond to the relationship first pointed out by Granger (1914) that Meniscotherium is absent from the lower strata in this area. However, an upper molar fragment of Meniscotherium was collected from locality 7409, which has not been traced directly into this section. Based on the field notes of Louis Jacobs from the summer of 1973, this locality is in Arroyo Blanco near locality 7411. Locality 7411 is very low in the section (third locality from the bottom), and, thus, neither Meniscotherium, nor any other genus, appears to be stratigraphically restricted. The fauna as a whole, therefore, appears to be relatively homogeneous at the generic level. Future analysis at the species level might yield some faunal "breaks" within the section which may lead to a better understanding of the evolution of particular genera. It is hoped that localities worked by other institutions can eventually be incorporated into this framework giving a more complete picture of the distribution of the animals in the area through time.

**Magnetic-polarity Stratigraphy**

Paleomagnetic samples were collected at 55 sites within the four stratigraphic sections: 24 in the Arroyo Blanco section, 7 in Simpson's Section 2, 5 in the Lindrith Road section, and 19 in the Regina Rincon section. Three, and sometimes four, oriented hand samples were collected at
each site following the technique of Johnson, Opdyke, and Lindsay (1975) and Lindsay and others (in press). An attempt was made to maintain a stratigraphic sampling interval of ten feet. However, many lithologies encountered at such an interval were inappropriate for sampling, and the average sampling interval is closer to 15-20 feet. Sampling was done in the finest-grained lithologies available, the majority of which were claystone or fine siltstone. Some coarse silts to fine sandy silts were also collected. Most outcrops were highly weathered, and an attempt was made to obtain the freshest samples possible by digging down to hard, fresh rock.

Preparation and Measurement

The samples were prepared and measured at The University of Arizona Paleomagnetism Laboratory. As described in Lindsay, Butler, and Johnson (in press):

...the oriented hand samples were trimmed with a dry-cutting carborundum wheel and placed in clear plastic micromount boxes of outside dimensions 1" X 1" X 3/4". The volume of the contained sample is approximately 4 cm$^3$. The orientation accuracy of this sampling procedure is estimated at $\pm 5^\circ$.

All measurements of remanent magnetism were done on a cryogenic magnetometer (Superconducting Technology model C-102) with computer interface for real-time data acquisition and analysis. The noise level of the instrument is less than 1 x $10^{-7}$ gauss cm$^3$ allowing measurement of any 4 cm$^3$ sample with an intensity of remanent magnetism greater than 3 x $10^{-8}$ gauss. Alternating field (AF) demagnetization was performed with a Schonstedt model GSD-1 single-axis demagnetizer.
Magnetic Properties and Polarity Determinations

Progressive, or stepwise, alternating field (AF) demagnetization to peak fields of 500 oersteds (oe) was performed on selected samples representing a variety of lithologies. Changes in direction of magnetization with progressively higher alternating field were analysed by plotting the directions on vector demagnetization diagrams. Thermal demagnetization to 400-600 °C was also performed on several samples.

These studies reveal that samples from the San José Formation are more complex mineralogically than samples collected from Cretaceous and Paleocene rocks in the San Juan Basin (see Lindsay, Butler, and Johnson, in press; Butler and Taylor, 1978; Taylor and Butler, 1980). The progressive demagnetization studies indicate that the carrier of the primary natural remanent magnetism (NRM) has a significant proportion of its remanent coercivity spectrum in the 200-500 oe range. This type of behavior is expected from fine-grained magnetite. All samples were then AF demagnetized at 150-250 oe and, in general, samples showed a primary NRM which was isolated at 250 oe with secondary components having remanent coercivities generally less than 250 oe. This suggests that the primary NRM at most sites is a depositional remanence (DRM) formed at the time
of deposition of the sediments or during consolidation shortly thereafter.

However, some samples did not respond to AF demagnetization in fields of 500 oe and higher. Upon thermal demagnetization their direction and intensity of magnetism still did not change at temperatures above the Curie temperature of magnetite (578 °C). This type of behavior suggests that some samples have a significant fraction of hematite. The hematite most likely originated from chemical alteration of the original detrital magnetite or other iron-bearing minerals within the sediment, resulting in a secondary chemical remanence (CRM). However, this alteration has not gone to completion in the samples and in the majority of them the original DRM is the primary remanence that is measured.

Thus, both magnetite and hematite are undoubtedly present in some of the samples. However, careful inspection and analysis of each site can still lead to reliable polarity determinations for most sites. As seen in the following section, resulting magnetozones are duplicated between the four stratigraphic sections, suggesting that the polarity zones are stratigraphically controlled, rather than being controlled by lithology of the site. This independence of lithology lends credence to the polarity determinations.
Site mean NRM intensities range from $6.7 \times 10^{-6}$ gauss to $3.3 \times 10^{-7}$ gauss with a geometric mean of $8.2 \times 10^{-7}$ gauss. Site mean intensities after AF demagnetization at 150-250 oe range from $2.12 \times 10^{-6}$ gauss to $1.33 \times 10^{-7}$ gauss with a geometric mean of $7.0 \times 10^{-7}$ gauss. There is significant scatter in site mean directions (Fig. 9) due to the complex mineralogies of some samples. Polarity determinations must, therefore, have varying degrees of reliability, and the class structure presented by Lindsay and others (in press) has been adopted for this study. This class structure allows the presentation of polarity data for each site in a hierarchy which represents the total reliability of the data. Class I sites are those which are most reliable for polarity determinations, and Class IV sites are those which offer little or no useful information for polarity determinations.

Class I sites have clustering of sample directions of magnetization which are statistically significant from selection from a population of randomly directed vectors at the 95% confidence level (Watson, 1956; Irving, 1964; Vincenz and Bruckshaw, 1960). Statistical significance at the 95% probability level means that the vector average ($R$) for a given site is greater than or equal to 2.62 for sites with three samples, and greater than or equal to 3.10 for sites with four samples. This implies that there is only a
Figure 9. Site mean directions after AF demagnetization to 150-250 oersteds.
5% probability that the 3 or 4 directions from a Class I site were selected from a random population of directions. Class II sites are those which are not statistically significant from random directions at the 95% confidence level, but all but one of the samples have concordant directions. Class III sites have strung distributions, but the directions change upon AF demagnetization in a systematic way so that the polarity of the stable component can be inferred from the demagnetization behavior. Class IV sites are those whose directions yield no useful information for making polarity determinations. Thus, when assigning a polarity and class to a site, it is first necessary to test the mean direction statistically for randomness and the inspect the AF demagnetization characteristics and behavior for the site.

Results

The class structure for the 55 sites in the San José section consists of 23 Class I sites, 7 Class II sites, 8 Class III sites, and 17 Class IV sites. Thus, a total of 38 sites yield useful and reliable information for polarity determinations, while 17 sites yield no useful information. The large number of Class IV sites is a direct reflection of the complex nature of this 17 sites. The polarity determination and class designation for each site within each section is shown in Figure 10. These sections are placed
Figure 10. Magnetic-polarity zonation of lithologic sections and the resulting composite magnetic section.

The polarity (p) and class designation (c) for each site in each section are shown. The polarity zones in each section are determined by combining adjacent like-polarity sites. Black polarity zones are formed by normal polarity sites; white polarity zones of reversed polarity sites. The composite section is formed by combining the zonations of the four sections.
Figure 10. Magnetic-polarity zonation of lithologic sections and the resulting composite magnetic section.
relative to the stratigraphic position obtained by tracing the marker beds between the sections. From this information polarity zones are established for each section. The sections are then combined to establish a composite magnetic section (far right in Figure 10).

It is of major importance to note that the polarity zones are duplicated at the same stratigraphic level in each section. The reversed polarity zone (B-) in Simpson's Section 2 is duplicated in the Lindrith Road section (B-) and in the Regina Rincon section (D-) at approximately the same stratigraphic level. This reversed polarity zone is represented by only one reversed polarity site within each section. A normal polarity zone above this reversed polarity zone is complete in both the Lindrith Road section (C+) and in the Regina Rincon section (E+). Also note the overlap of the lowermost normal polarity zone at the base of the Regina Rincon section (A+) with the top of the Arroyo Blanco section (B+). Unfortunately, it is not possible to sample lower in the Regina Rincon area to find the base of this normal polarity zone in that section. This duplication of polarity zones enhances the reliability of the polarity determinations and suggests that the stratigraphic correlations of the sections are accurate.
Correlation of the San José Section to the Magnetic-polarity Time Scale

A major aim of this study is to correlate the San José composite magnetic section to the magnetic-polarity time scale (see LaBrecque, Kent, and Cande, 1977). The first consideration in making this correlation is to note the pattern of polarity zones in the San José section (Fig. 10). The most obvious and significant feature of this pattern is the long reversed polarity zone which comprises the entire lower half of the section from its base approximately to the 380 foot level. A relatively long, dominantly normal polarity zone extends from 380 feet to 630 feet. Two very short reversed polarity zones occur within this long normal polarity zone, both being represented by only one reversed polarity site in any one section. From 630 feet to 670 feet is another reversed polarity zone with an overlying normal polarity zone of approximately the same thickness. There is one reversed polarity site at the very top of the section.

Next to be considered is paleomagnetic work reported from the Paleocene of the San Juan Basin by Lindsay, Jacobs, and Butler (1978), Butler and Taylor (1978), Taylor and Butler (1980), and Lindsay, Butler, and Johnson (in press). Lindsay, Jacobs, and Butler (1978, p. 426) correlate the uppermost normal polarity zone in the Nacimiento Formation
(Kutz Canyon section) with marine magnetic anomaly 25 (Fig. 11). Unfortunately, no fossils have been recovered from strata this high in the formation. If the boundary between the Nacimiento Formation and the overlying San José Formation is not time-transgressive, the San José section must be younger than anomaly 25. This relationship, however, need not be true and is a minor consideration.

The important consideration resulting from these studies is that Torrejonian (middle Paleocene) fossils occur in strata of the Nacimiento Formation correlated with marine magnetic anomaly 26 (Fig. 11). Therefore, the San José section, which contains fossils assigned to the Wasatchian (early Eocene), must be younger than anomaly 26, presumably with the Tiffanian and Clarkforkian Land Mammal Ages intervening.

Similar studies in the Bighorn Basin and Clark's Fork Basin of Wyoming as reported by Butler and Lindsay (1979) and Butler, Gingerich, and Lindsay (in press) suggest that Tiffanian fossil localities correlate with magnetic anomaly 26 and the reversed polarity intervals immediately preceding and following anomaly 26 (Fig. 11). Clarkforkian localities correlate with marine magnetic anomaly 25 and the reversed polarity interval immediately following it. Lower Wasatchian localities also correlate with the reversed polarity interval between anomalies 25 and 24.
Figure 11. Correlation of the San Juan Basin Torrejonian and the Bighorn Basin Tiffanian, Clarkforkian, and Wasatchian to the magnetic-polarity time scale.
Summarizing these considerations, the magnetic-polarity time scale should contain a sequence of reversed and normal polarity intervals similar in character to the sequence in the San José composite magnetic section, dominated by a relatively long reversed polarity interval. This sequence should be found near the Paleocene-Eocene boundary and be younger than, but close to, anomaly 25.

Inspection of the magnetic-polarity time scale presented by La Brecque, Kent, and Cande (1977) reveals that the reversed polarity interval immediately above anomaly 25 is quite long relative to any other nearby intervals (Fig. 12). Knowing that lower Wasatchian mammals in Wyoming correlate with this long reversed polarity interval, I suggest that the long reversed polarity zone at the base of the San José section is also correlative with this long reversed polarity interval. Therefore, I correlate the transition from reversed to normal polarity at the 380 foot level in the San José section with the base of anomaly 24 (Fig. 12). It is not clear, however, where the upper boundary of anomaly 24 occurs in the San José section, if indeed it does. The shortness of the reversed polarity zones at the 450 and 550 foot levels suggests that they might not be represented within the magnetic anomaly pattern of the sea-floor. Assuming this to be the case, I tentatively correlate the transition
Figure 12. Correlation of the San José composite magnetic section to the magnetic-polarity time scale.
from normal to reversed polarity at the top of the San José section with the upper boundary of anomaly 24.

In summary, the strongest line of evidence supporting the correlation I have presented is that lower Wasatchian mammals occur in the long reversed polarity interval between anomalies 24 and 25 as represented by strata in the Bighorn Basin of Wyoming. This suggests that the long reversed polarity zone at the base of the San José composite magnetic section can be correlated to this same reversed polarity interval, with the base of anomaly 24 occurring approximately at the 380 foot level in the section. The correlation of the upper boundary of anomaly 24 is not as strong and may be changed or corroborated when further paleomagnetic evidence from higher in the Bighorn Basin section is available.
Granger (1914) placed a "horizontal" boundary between his Almagre and Largo beds at the first appearance of *Meniscotherium*. This led to the assumption that the Largo fauna was stratigraphically higher, and therefore younger, than the Almagre fauna. This has led most subsequent researchers to correlate these fauna to mutually exclusive time periods within the Wasatchian. Simpson (1948b, p. 369) stated that, although it was not clear as far as his study went, the lowest levels of the Largo facies might grade laterally in places into the Almagre facies. The stratigraphic relationships resulting from this study suggest that Simpson was indeed correct. Figure 13 shows that Largo strata occur at stratigraphically lower horizons in the Arroyo Blanco area than in the Regina area and, therefore, the transition from Almagre to Largo strata is time transgressive. In any given section, Largo strata do, indeed, overlie Almagre strata, but Almagre strata are also replaced laterally by Largo strata to the north, northwest, and west. Also in any given section, strata higher in the section containing *Meniscotherium* overlie strata lower in the section.
Figure 13. Generalized stratigraphic relationship of the Almagre and Largo facies.
lacking *Meniscotherium*. These occurrences, however, do not correspond precisely with the lithologic facies.

Thus, the relationship noted by Granger (1914) holds true locally, but the transition from Almagre to Largo strata does not occur at the same stratigraphic level in all areas, nor does it correspond precisely to the first appearance of *Meniscotherium* in all areas. The interdigitation of facies suggests that the Almagre and Largo were contemporaneous throughout much of the time of their existence and were intergradational laterally as well as vertically. It appears that as sediment built up over the area, the interface between the Almagre and Largo facies "migrated" southward through time as the Largo gradually encroached upon the Almagre facies. Thus, *Meniscotherium* was abundant to the north during times when it was absent or rare farther south.

In view of this relationship, the Largo "fauna" is not simply superposed above the Almagre "fauna" and they do not represent mutually exclusive time periods, although higher occurrences are obviously younger. They were not two distinct faunas at all, but represent faunal facies which broadly, but not precisely, correspond to the lithologic facies. Table I and Figure 13 suggest that there is no real stratigraphic or lithologic segregation of genera in this area. Differences in abundance and diversity of taxa between the facies suggest a difference in depositional
environment and ecology between the two facies (Simpson, 1948b, p. 379-382). Thus, the overall fauna should be considered as one entity, evolving slowly through time as environments shifted. I therefore suggest that the names Almagre and Largo be reserved for the lithologic facies and their corresponding roughly contemporaneous biofacies, and that these names should not be retained for "local faunas".

Consideration of the San José fauna as a whole, rather than as representing mutually exclusive time periods, still does not lead to unambiguous correlation to Wyoming faunas, mainly because of the lack of characteristic non-equid perissodactyls. This is undoubtedly due to the geographic separation of the two areas. It is known that Graybullian (lower Wasatchian) mammals in Wyoming correlate with the long reversed polarity interval between anomalies 24 and 25. The lower boundary of Graybullian falls within this interval, but the upper boundary is not known relative to the magnetic-polarity time scale. This boundary could be within this same reversed interval, within anomaly 24, or even younger polarity intervals.

The San José fauna correlates with the upper part of the long reversed polarity interval between anomalies 24 and 25, and to at least the lower part of anomaly 24. It cannot be stated for certain whether the paleomagnetically sampled San José and Bighorn Basin sections overlap in time, and,
therefore, the San José section may represent Graybullian in part, or may in fact be totally younger. Thus, the Graybullian, Lysitean, and Lostcabinian of Wyoming must be identified and delimited relative to the magnetic-polarity time scale before precise correlation of the San José fauna within these subdivisions of Wasatchian can be made.
REFERENCES CITED


REFERENCES CITED


