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GEOLOGY AND MAMMALIAN BIOSTRATIGRAPHY OF A PART OF THE NORTHERN CADY MOUNTAINS, MOJAVE DESERT, CALIFORNIA

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GEOLOGY AND MAMMALIAN BIOSTRATIGRAPHY OF A PART OF THE NORTHERN CADY MOUNTAINS, MOJAVE DESERT, CALIFORNIA

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ABSTRACT

Approximately 1250 ft (381 m) of interbedded basalt, tuff, and volcaniclastic sedimentary rock crop out in the northern Cady Mountains, Mojave Desert, California. These rocks are assigned to the Hector Formation of Woodburne, Tedford, Stevens, and Taylor (1974). Sediments in the Hector Formation accumulated in alluvial and lacustrine depositional environments. These environments occurred in a paleogeographic setting that incorporated a basin-plain complex of lakes, ponds, and marshes; a gently-inclined alluvial plain complex; and a distal alluvial-fan complex. Sediments deposited in these environments lapped onto an erosional surface that was developed on an older volcanic and sedimentary terrain. This terrain provided epiclastic volcanic and granitic constituents to the Hector Formation. Intermittent volcanism of basaltic and rhyolitic composition accompanied deposition of the alluvial/lacustrine sediments. The volcanic events are represented by a basalt flow and a rhyolitic ash-flow tuff, and by beds of vitric air-fall tuff that occur intermittently throughout the sequence.

Radiometric age determinations and mammalian fossils indicate that the Hector Formation in the northern Cady Mountains is early Miocene in age. Three volcanic units have yielded ages of 22.9 ± 0.4, 18.6 ± 0.2, and 17.9 ± 0.3 m.y.b.p. Fossil mammals indicate an age span of early Hemingfordian through late Hemingfordian. The Hector Formation thus spans late Arikareean through at least late Hemingfordian time.

Mammalian fossils from the Hector Formation are grouped into two local faunas: (1) the Lower Cady Mountains local fauna, and (2) the Upper Cady Mountains local fauna. The Lower Cady Mountains local fauna contains three taxa: *Merychyus* (*Merychyus*) sp., cf. *M.* (*M.*) *calaminthus*, Aletomerycinae, and Merychyinae The Upper Cady Mountains local fauna contains 7 taxa: *Proheteromys sulculus*, *Tomarctus* sp. cf. T. *hippophagus*, *Merychippus carrizoensis*, cf. *Diceratherium* sp., cf. *Aepycamelus* sp., *Merycodus* sp., and "*Miolabis*" cf. "*M.*" *tenuis*. The Lower Cady Mountains local fauna is middle Hemingfordian in age. The Upper Cady Mountains local fauna is late Hemingfordian in age.

INTRODUCTION

This paper discusses the geology and vertebrate paleontology of a portion of the northern Cady Mountains, Mojave Desert, California (fig. 1). The study area is about seven square miles (11 square km) in extent, and occurs in Tps. 10 and 11 N., Rs. 6 and 7 E., of the Cady Mountains 15 minute topographic quadrangle. Here, approximately 1250 ft (381 m) of volcaniclastic sedimentary rock with minor interbedded basalt and tuff crop out in a gently folded, eastward-plunging syncline that was subsequently broken by normal faults. The sedimentary rocks contain vertebrate fossils of early Miocene (early Hemingfordian through late Hemingfordian) age. Provincial usage of Tertiary Epochs follows that of Wood, and others, 1941. The sedimentary and volcanic rocks are herein designated as the northern Cady Mountains sequence of the Hector Formation as defined in the southern Cady Mountains by Woodburne, Tedford, Stevens and Taylor (1974). The type section of the Hector Formation is located about 8 mi (13 km) southwest of the study area. Although outcrops of the unit are not continuous between the southern Cady Mountains and the study area, extension of the name Hector Formation into the northern Cady Mountains is justified because the stratal sequence here is partly time-equivalent with, shared a common source area with, and is lithologically similar to portions of the type Hector.

This study was undertaken primarily to determine the geologic setting of fossil mammals that occur in the northern Cady Mountains, and to evaluate the contribution of these fossils to our understanding of the biostratigraphic succession of Miocene mammals in the Mojave Desert province. Fossil-bearing sedimentary rocks of Miocene age occur at several localities throughout the central Mojave Desert. As shown in figure 2, these sedimentary sequences range from late Arikareean through Barstovian in age, and most sequences contain more than one local vertebrate faunal assemblage.

When considered as a whole, the succession of Miocene fossil mammals in the Mojave Desert is incomplete because no single outcrop series contains all of the mammalian faunas in succession. For example, late Hemingfordian and Barstovian sedimentary rocks in the Mud Hills and in the Alvord Mountains contain local faunas that are stratigraphically isolated from older fossil assemblages. Likewise, late Arikareean and early Hemingfordian assemblages in the southern Cady Mountains and early or middle Hemingfordian assemblages in the Kramer Borate district are isolated from their stratigraphic successors and precursors. In short, there is an obvious need for a sedimentary sequence in the central Mojave Desert that is fossiliferous, that spans Arikareean, Hemingfordian, and Barstovian time, and that would demonstrate continuous biostratigraphic relations between key fossil genera and species. As shown in figure 2, rocks in the northern Cady Mountains come close to providing such a continuous sedimentary sequence.

Radiometric age determinations from the northern Cady Mountains suggest that sedimentary rocks between dated volcanic units range in age from 22.9 to 17.9 m.y.b.p. Sedimentary rocks subjacent and superjacent to the dated volcanic units span a greater interval of time. Thus, the northern Cady Mountains sequence spans at least late Arikareean through late Hemingfordian time, and may very well span early Arikareean through earliest Barstovian time. Reconnaissance fossil mammal collections obtained by previous workers indicated the

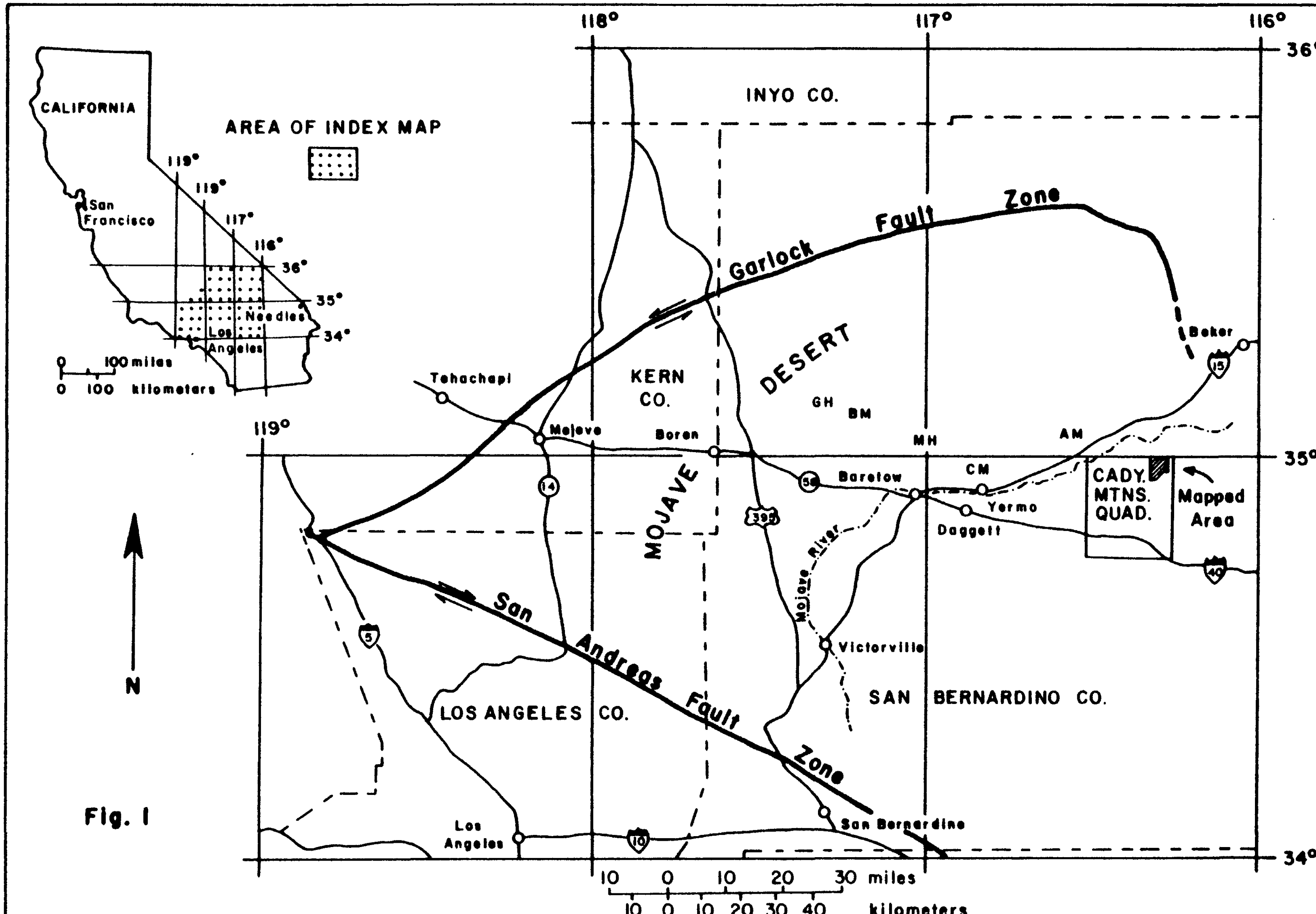

Fig. 1

Figure I.— Index map, northeastern Cady Mountains and vicinity, Mojave Desert, Southern California. AM, Alvord Mountains; CM, Calico Mountains; MH, Mud Hills; GH, Gravel Hills; BM, Black Mountain.

presence of early or middle Hemingfordian and late Hemingfordian faunal elements, and study of these preliminary collections demonstrated the biostratigraphic potential of the northern Cady Mountains sequence. Subsequent collections by the author and by other workers have augmented the number of fossil specimens and have increased the known stratigraphic distribution of key faunal elements. So far, however, collecting has yielded only Hemingfordian fossils: no late Arikareean or early Barstovian mammalian faunas have been recovered. The biostratigraphic potential of Miocene rocks in the northern Cady Mountains still exists, however, particularly when these rocks are considered together with older fossil-bearing Miocene rocks in the nearby southern Cady Mountains. The physical stratigraphy and the structural geology of the fossil-bearing rocks were documented in order to determine this stratigraphic potential.

In addition to their paleontologic significance, rocks in the northern Cady Mountains provide insight into sedimentologic, volcanic, and paleogeographic patterns in the central Mojave Desert during Miocene time. The time/space evolution of middle and late Tertiary tectonism, volcanism, and sedimentation in the Mojave Desert region is not yet well understood, and Miocene rocks in the northern Cady Mountain contribute to our understanding of these regional developments.

The objective of this report is fourfold: (1) to describe the lithology, stratigraphy, and depositional history of Miocene rocks exposed in the northern Cady Mountains; (2) to document the areal distribution of these rocks, paticularly the distribution of key marker beds that occur in the sequence; (3) to discuss the taxonomy, biostratigraphy, and correlation of fossil mammals that occur in the sequence; and (4) to discuss paleogeographic relations between Miocene rocks in the northern Cady Mountains and other Miocene sedimentary/volcanic sequences that occur in the central Mojave Desert region.

Previous Investigations

Published geological investigations in the northern Cady Mountains are limited to reconnaissance studies. The study area was discussed briefly by Bassett and Kupfer (1964) in a paper reviewing the geology of a large portion of the southeastern Mojave Desert that had been mapped earlier in reconnaissance (Kupfer and Basett, 1962). Part of the northern Cady Mountains was mapped by Dibblee and Bassett (1966b). Rocks in the study area informally designated Ts and Tsb by these authors are herein assigned to the northern Cady Mountain sequence of the Hector Formation. A 15 to 20 mi^2 (39 to 52 km^2) area which lies immediately northwest of the study area was mapped in detail by Moseley (1978), but Moseley's data have not been published.

Fossils were first reported from the northern Cady Mountains by Bassett and Kupfer (1964, p. 21-22). In 1954 vertebrate remains were collected from their KD-1 fossil locality by Richard H. Tedford (now with the American Museum of Natural History, New York), and were identified by him as a "paleomerycid species and an oreodont species not older than early Miocene and not younger than late Miocene" (Bassett and Kupfer, 1964, p. 22). Bassett and Kupfer state that additional fossil material, principally camelid remains, had later been collected by L.J.P. Muffler from both their KD-1 and KD-2 localities. Subsequent to the studies by these authors, fossil collecting in the northern Cady Mountains

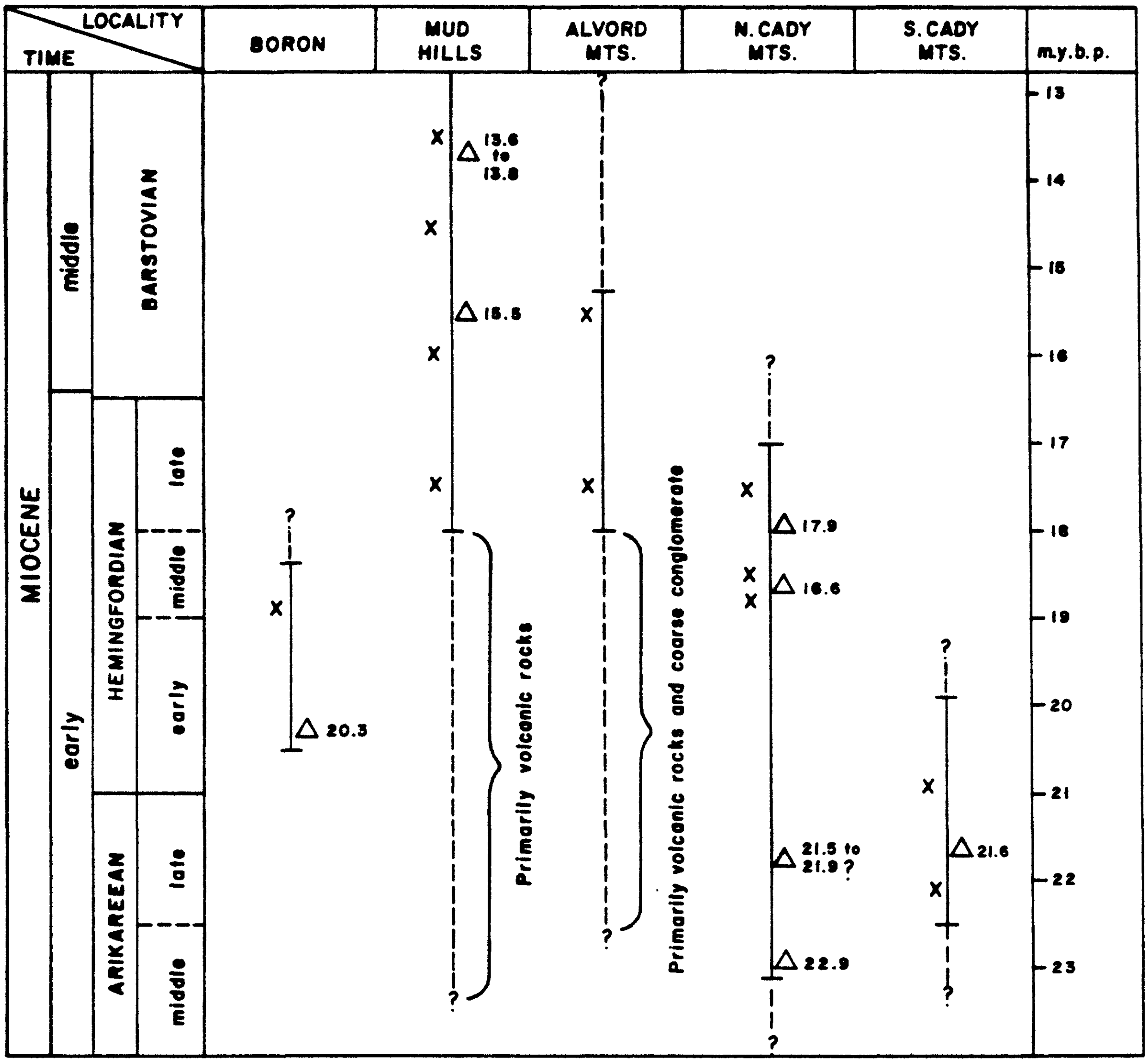

FIGURE 2

I = Rocks of this age verified on the basis of fossils (X) or on the basis of K/Ar radiometric dates (Δ)

¦ ? = Rocks of this age probably present, but not confirmed by either fossils or radiometric age determinations

Δ = New and existing radiometric dates discussed in this report

Figure 2.--Diagram summarizing the stratigraphic ranges of key Miocene stratal sequences in the central Mojave Desert. The sedimentary/volcanic sequence in the northern Cady Mountains has the potential for yielding a continuous succession of late Arikareean through (?) earliest Barstovian mammalian faunas. Data in figure from: Whistler, 1965; Lewis, 1964, 1968; Lindsay, 1972; Byers, 1960; Woodburne and others, 1974; and this report. Time divisions follow U.S. Geological Survey and Ryan and others, 1974. Where necessary, K/Ar ages have been recalculated according to Dalrymple (1979, table 2, p. 559).

has been carried out intermittently by field parties from the Department of Earth Sciences of the University of California, Riverside. The U. S. Geological Survey subsidized fossil collecting during the summer of 1967. The taxonomic makeup of these initial vertebrate fossil collections suggested that a detailed study of their biostratigraphy and geologic setting would contribute to our understanding of the Miocene fossil mammal succession in the central Mojave Desert area.

Methods and Terminology

Geological mapping in the northern Cady Mountains was done on aerial photographs having a scale of approximately 1:8000. The geology was transferred to a 1:8000 enlargement of the U.S. Geological Survey Cady Mountains 15 minute topographic quadrangle.

In 1977, the International Union of Geological Sciences Subcommission on Geochronology published new constants for radioactive decay and for abundance of ^{40}K, to be used in the calculation of potassium-argon (K1Ar) ages (Steiger and Jager, 1977). In this report, the author found it necessary to cite K/Ar dates which had been calculated originally using the old western constants. In order to facilitate the comparison of age data, the dates calculated with the old western constants have been recalculated using the conversion table of Dalrymple (1979, table 2, p. 559). The following dates have been recalculated, and only the recalculated ages will be cited in the text:

Published date	Recalculated date	Formation	Reference
22.3 ± 0.4 m.y.	22.9 ± 0.4 m.y.	Hector Fm.	Miller, 1978
17.4 ± 0.3 m.y.	17.9 ± 0.3 m.y.	Hector Fm.	Miller, 1978
21.3 ± 0.3 m.y.	21.9 ± 0.3 m.y.	Hector Fm.	Armstrong and Higgins, 1973
19.8 ± 0.7 m.y.	20.3 ± 0.7 m.y.	Saddleback Basalt	Armstrong and Higgins, 1973
23.1 ± 2.3 m.y.	22.5 ± 2.3 m.y.	Unnamed	Nason and others, 1979
21.0 + 5% m.y.	21.6 ± 5% m.y.	Hector Fm.	Woodburne and others, 1974
21.3 m.y.	21.9 m.y.	Harrison Fm.	Evernden and others, 1964
15.1 m.y.	15.5 m.y.	Barstow Fm.	Evernden and others, 1964
17.6 m.y.	17.1 m.y.	Kinnick Fm.	Evernden and others, 1964
13.2 to 13.4 m.y.	13.6 to 13.8 m.y.	Barstow Fm.	Lindsay, 1972

In this report, the author follows the major stratigraphic and time divisions of the U.S. Geological Survey, which places the Oligo-Miocene boundary at about 24.0 million years. The author follows Ryan and others (1974) in placing the early-middle and middle-late Miocene boundaries at 16.4 and at 12.0 million years, respectively.

In this report the term volcaniclastic refers to sedimentary rocks whose framework grains are mainly volcanogenic in origin. These grains may be both pyroclastic and epiclastic in derivation. Pyroclastic refers to fresh magmatic ejecta in the form of tephra that is explosively erupted from a vent, and that subsequently is incorporated into the rock record with or without an interim history of penecontemporaneous reworking by sedimentary or aeolian processes.

The terms tuff and tuffaceous are herein used to designate rocks composed of pyroclastic materials. Epiclastic refers to clastic detrital framework grains derived by weathering and erosion of a pre-existing volcanogenic source terrain. Epiclastic and pyroclastic constituents can occur in the same volcaniclastic sediment body, although it may be difficult to distinguish epiclastic vitric grains from pyroclastic vitric grains.

Terminology for bedding thickness follows Ingram (1954): laminated (<1.0 cm); very thin bedded (1.0 to 4.0 cm); thin bedded (4.0 to 10.0 cm); medium bedded (10 to 30 cm); thick-bedded (30 to 100 cm); and very thick-bedded (>100 cm). Stratigraphic thicknesses are given both in feet and in meters.

The following abbreviations are used in the narrative portion of this report:

USGS = United States Geological Survey

UCR = University of California, Riverside

m.y.b.p. = million years before present

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The author gratefully acknowledges the aid and advice given by the faculty of the Department of Earth Sciences, University of California, Riverside, especially Michael O. Woodburne and Paul T. Robinson. Richard H. Tedford of the American Museum of Natural History (AMNH), New York, checked measurements of type specimens in the collections of the AMNH, and graciously allowed the use of unpublished biostratigraphic data collected in the northern Cady Mountains. Donald E. Savage and Garniss Curtiss, both of the University of California, Berkeley, allowed the writer to cite unpublished radiometric age determinations obtained by them from volcanic units in the northern Cady Mountains.

In addition, the writer gratefully acknowledges the help of several workers at the U.S. Geological Survey, Menlo Park, California, who in various ways aided in the preparation of this manuscript. Miles L. Silberman and Janet L. Morton provided radiometric age determinations from rocks collected by the writer in the study area. Dennis B. Burke discussed regional geologic interpretations of the Mojave Desert Province with the author. Jonathan C. Matti reviewed the manuscript. Kenji Sakamoto helped to prepare the vertebrate fossil specimens for photographing and instructed the writer about effective ways to photograph these specimens. Special thanks are extended to Charles A. Repenning, who generously donated his time for discussions, who provided comparative fossil and recent materials from the U.S. National Museum collections, who helped to photograph the specimens, and who reviewed this manuscript.

REGIONAL GEOLOGIC SETTING

The Cady Mountains occur in the central part of the Mojave Desert geomorphic province. This province is bounded on the north by the Garlock Fault zone and on the southwest by the San Andreas Fault zone (fig. 1). To the east, the Mojave Desert province merges with the Basin-and-Range province, and a distinct structural and geomorphic boundary between the two provinces has not been defined.

The Mojave Desert is underlain by a regionally widespread crystalline basement complex that consists of several distinctive rock types. The oldest crystalline rocks are represented by Precambrian gneissoid terrains that now are exposed only locally. The gneissoid rocks originally formed a widespread basement platform upon which late Precambrian and Paleozoic sedimentary rocks of the Cordilleran miogeocline and cratonal shelf were deposited (Burchfield and Davis, 1972, 1975). The gneissic and sedimentary rocks were subsequently intruded by granitoid rocks accompanied by penecontemporaneous volcanism. Many workers have suggested that the plutonic rocks were emplaced in Jurassic and Cretaceous time, and are genetically related to and structurally continuous with the Sierra Nevada batholith (Dibblee, 1967; Burchfiel and Davis, 1972, 1975, and references therein). The Mesozoic granitoid rocks are now the most widespread rock-type of the crystalline basement terrain in the western and central Mojave Desert; the Paleozoic sedimentary rocks are represented by local outliers and by metamorphic roof pendants. Intrusive and extrusive volcanic and metavolcanic rocks of presumed Triassic age form the remaining component of the basement complex, and these also occur as roof pendants associated with the granitoid intrusive rocks. The volcanic and metavolcanic rocks are variously assigned to the Hodge Volcanic Series, Sidewinder Volcanic Series, and Ord Mountain Volcanic Series (Dibblee, 1967).

Sedimentary and volcanic sequences of (?) late Oligocene and Miocene age are scattered throughout the central Mojave Desert province (fig. 3). Topographic basins receiving these sedimentary/volcanic sequences evolved directly upon the crystalline basement complex: older Paleocene, Eocene, and documented lower and middle Oligocene rocks are unknown in the central Mojave Desert, hence the early and middle Tertiary history of the region is poorly known. Likewise, the age of inception of upper Tertiary sedimentation, volcanism, and basin development is not clearly established. The oldest Tertiary volcanic rocks so far dated have yielded radiometric ages of about 23 m.y.b.p. (23.1 $\pm$ 2.3 m.y.b.p., Nason and others, 1979; 23.1 $\pm$ 0.2 m.y.b.p., Burke and others, in prep.; older than 22.9 $\pm$ 0.4 m.y.b.p., this report). However, thick sequences of volcanic and sedimentary rocks in places underlie these dated units, and the inception of basin development probably occurred prior to 23 m.y.b.p. In this report, basin-inception, sedimentation, and volcanism are believed to have developed more or less simultaneously throughout the central Mojave Desert, and may have begun in late Oligocene or earliest Miocene time (prior to 23 m.y.b.p.).

The volcanic/sedimentary basins seem to have originated as downwarped sags and troughs that may or may not have been locally fault-bounded or partially fault-bounded. The role that extensional faulting played during the evolution of these sedimentary/volcanic basins is not clear: although some workers have recognized high-angle normal faulting conterporaneous with, or at least temporarily associated with, sedimentation and volcanism (e.g. McCulloh, 1952, p. 112, 119;

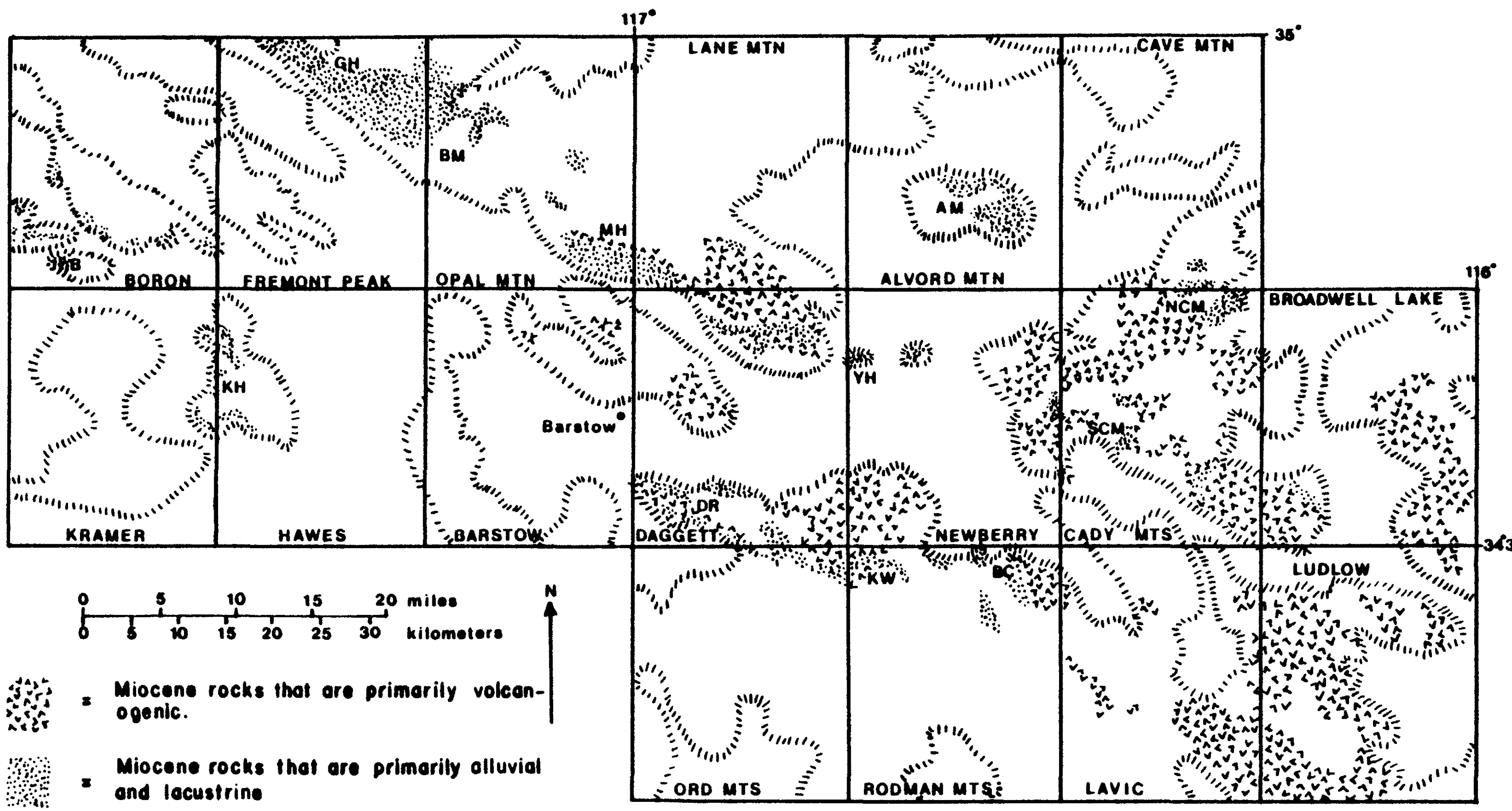

Figure 3.--Diagram summarizing the areal distribution of major outcrop of Miocene and (?) latest Oligocene sedimentary/volcanic sequences in the central Mojave Desert. The grid network is defined by the boundaries of 15 minute quadrangles (Cady Mountains, Lavic, Dagget, etc.). The figure also shows mountain ranges that are mentioned in the text: AM, Alvord Mountains; BC, Box Canyon; BM, Black Mountain; DR, Daggett Ridge; GH, Gravel Hills; KH, Kramer Hills; KW, Kane Wash; MH, Mud Hills; NCM, northern Cady Mountains; SCM, southern Cady Mountains; YH, Yermo Hills.

Byers, 1960, p. 47, 58), other workers have suggested that faulting played a minimal role in the development of the basins (e.g., Dibblee, 1968, p. 41; 1971). In either case, the depositional troughs were flanked by higher-standing terrains underlain by the crystalline basement complex and mantled locally by tephra and flows derived from volcanic centers. The older crystalline rocks and the volcanic centers were the sources for epiclastic and pyroclastic constituents that accumulated in the (?) late Oligocene and Miocene depositional basins.

Time-space patterns of (?) late Oligocene and Miocene sedimentation and volcanism in the central Mojave Desert are not understood clearly. At many localities a superpositional succession exists where a thick sequence of prevailingly volcanogenic rocks and associated coarse conglomerate and volcaniclastic sandstone is succeeded by a thinner sequence of prevailingly alluvial/lacustrine sedimentary rocks associated with subordinate tuff and lava flows.

Representative examples of the prevailingly volcanogenic suite include thick sequences of basalt, andesite, dacite, rhyolite, and coarse alluvial sedimentary rocks in the Bullion Mountains, Cady Mountains, Rodman Mountains, Newberry Mountains, and Daggett Ridge area (Dibblee, 1964a, b, 1966; Dibblee and Bassett, 1966a, b; Dibblee 1967a, b, c; appropriate rock units include Ta, Tf, Tt, Tb in these quadrangles). Also included in the volcanogenic suite are sequences of basalt, andesite, dacite, rhyolite, and coarse alluvial sedimentary rocks in the Calico Mountains and Mud Hills (Jackhammer and Pickhandle Formations; McCulloh, 1952; Dibblee, 1968, 1970).

Representative examples of the prevailingly alluvial/lacustrine suite include the Barstow Formation in the Gravel Hills, Mud Hills, and Calico Mountains (Dibblee, 1967d, 1968); the Clews Fanglomerate, Alvord Peak Basalt, Spanish Canyon Formation, and Barstow Formation in the Alvord Mountains (Byers, 1960); the Hector Formation in the southern Cady Mountains (Woodburne and others, 1974); previously unnamed rock units in the northern Cady Mountains (Ts and Tsb of Dibblee and Bassett, 1966b); and unnamed rocks in the Rodman Mountains, Newberry Mountains, and Daggett Ridge area (Tss, Tsg, Tst, Tsc, Tsf, Tsb, Tsh, Tsl, and Tsi of Dibblee, 1964a, b, 1970; Dibblee and Bassett, 1966a). All these units consist mainly of diverse suites of tuffaceous, feldspar-rich and tephra-bearing sandstone, siltstone, mudrock, and volcanic and granitic conglomerate. These rocks were deposited in a variety of alluvial and lacustrine sedimentary environments. Basalt, siliceous tuff, and uncommon andesite are locally important, but in total aspect, volcanism was considerably less significant in the prevailingly alluvial/lacustrine suite than in the prevailingly volcanogenic suite. This report discusses rocks that herein are grouped within the prevailingly alluvial/lacustrine suite.

As indicated above, the two distinctive suites of rock occur in superpositional sequence at many localities, and the two suites commonly are separated by an unconformity. Regional relationships between the two packages of rock have not been determined, however, mainly because adequate radiometric or paleontologic dates have not been established for the volcanogenic sequences. General similarities in superpositional sequence throughout the central Mojave Desert region suggest that an early calc-alkaline volcanogenic episode accompanied by coarse alluviation may have occurred during initial basin development. These early events gradually may have been succeeded by alluviation and diminishing volcanism of basaltic and rhyolitic character. Considerable temporal overlap between the two sequences probably occurred on a region-wide basis: the cessation of volcanic-dominated events and the onset of alluvial/lacustrine-dominated events probably varied through time and space, resulting in local unconformities and wholesale-regional interfingering of the two distinct suites of volcanogenic and sedimentary rocks. The age span of the prevailingly volcanogenic suite is not documented. The age span of the prevailingly alluvial/lacustrine suite also is not documented, but in this report it is believed to have commenced at least as early as 23 m.y.b.p. (early Miocene) and to have lasted to at least 13 m.y.b.p. (late Miocene). The degree of superposition versus the degree of interfingering of the two suites of rock presently cannot be assessed.

Most of the Miocene sequences of the prevailingly alluvial/lacustrine suite now are displayed in geographically isolated and areally restricted outcrop belts that are exposed as windows beneath younger Tertiary and Quaternary volcanic and sedimentary rocks (fig. 3). Miocene rocks of the study area in the northern Cady Mountains are a good example. Their present geographic isolation poses problems for the lithostratigraphic classification of the various sedimentary/volcanic sequences and for the interpretation of their mutual paleogeographic relations. Chief among these problems is the question of whether the various Miocene sequences shown in Figure 3 were deposited in one single depositional basin or in several geographically isolated intermontane basins.

Problems created by the existing geographic isolation of the various sedimentary/volcanic sequences are compounded by the fact that their original paleogeographic positions may have been shifted relative to each other by post-Miocene strike-slip faulting. A system of subparallel, northwest-trending faults occurs in the western and central Mojave Desert (Jennings and others, 1962; Rogers, 1967). The series of (?) late Oligocene and Miocene sedimentary/volcanic sequences occurs on various structural blocks within this fault system. Some workers have suggested that the faults are strike-slip structures, and a variety of evidence has been marshalled to support post-Miocene right-lateral motion on these faults (see discussion by Dibblee, 1961; 1967d, p. 115; Garfunkel, 1974, p. 1932). However, there is sharp disagreement between Dibblee and Garfunkel concerning the magnitude of displacement on individual strike-slip structures. The actual displacement on these faults must be evaluated before the regional paleogeographic setting of the various (?) late Oligocene and Miocene sedimentary/volcanic sequences can be reconstructed. These various problems are considered later in this report in the section on paleogeographic relationships.

Finally, paleogeographic relations between the various Miocene sedimentary/volcanic sequences possibly could have been disrupted by undetected low-angle detachment or denudation structures which may have shuffled the sequences relative to each other. Recent work has shown that parts of the eastern Mojave Desert are underlain by localized metamorphic core complexes, and by more widespread denudation sheets or detachment sheets separated from autochthonous rocks by zones of decollement and cataclasis (Davis and others, 1977; Davis and others, 1979; Coney, 1979). Some detachment sheets contain late Tertiary sedimentary/volcanic sequences, suggesting that denudation faulting occurred in the late Tertiary following deposition of Miocene sediments (Davis and others, 1977; Davis and others, 1979; Coney, 1979). If similar metamorphic core complexes and associated decollement structures are recognized in the central and western Mojave Desert, then Miocene sedimentary/volcanic sequences discussed in this report may prove to have been repositioned with respect to each other. Possible structures reported in the Newberry Mountains by Dokka (1977), but not discussed by Nason and others (1979), may represent this kind of decollement structure.

DESCRIPTIVE GEOLOGY OF THE NORTHERN CADY MOUNTAINS

Hector Formation

Stratigraphic Nomenclature

Gently dipping volcaniclastic sedimentary rocks and associated volcanic rocks of Miocene age in the study area are herein designated the northern Cady Mountains sequence of the Hector Formation. No formal lithostratigraphic name has previously been applied to these rocks, although Gardner (1941, p. 279) may have included them in the "Rosamond Series" of Hershey (1902) when he alluded to "a thick volcanic section" in the Cady Mountains "north of the National Old Trails Highway." As detailed by Dibblee (1958, p. 135-136; 1968, p. 26-27), Hershey (1902) applied the name "Rosamond Series" in the Rosamond Hills to a sequence of unfossilferous volcaniclastic and volcanic rocks whose age was poorly understood. The term "Rosamond Series" was subsequently extended indiscriminately to various sedimentary/volcanic sequences of Tertiary age throughout the Mojave Desert Province (e.g., Baker, 1911; Hulin, 1925; Gardner, 1941). Because of its confusing and indiscriminant usage, the term "Rosamond Series" has been abandoned by the U.S. Geological Survey.

Application of any formal stratigraphic nomenclature to Miocene rocks in the northern Cady Mountains poses a problem in operational stratigraphic procedure. As summarized above, several Miocene sedimentary/volcanic sequences occur in the central Mojave Desert within a rectangular area that is approximately 80 by 30 mi (128 by 48 km) in dimension (fig. 3). These sequences overlap in age to varying degrees, and they are similar in general lithology and overall stratigraphic succession. They do, however, exhibit local variations in stratigraphic sequence and in detailed lithology. Together, these successions all seem to record mainly alluvial/lacustrine sedimentation accompanied by relatively limited contemporaneous volcanism - events that characterize the prevailingly alluvial/lacustrine suite described above. Thus, the nomenclatural problem in the northern Cady Mountains is whether the Miocene rocks should be assigned to a new lithologic unit or to an existing lithologic unit.

Since many of the stratal sequences in the central Mojave Desert region have been formally named, I have tried to work within this existing nomenclatural framework and thereby keep the number of new rock names to a minimum. Seven formational names have been applied to the lower and middle Miocene rocks in the central Mojave Desert region: (1) the Jackhammer Formation and (2) the Pickhandle Formation of McCulloh (1952); (3) the Barstow Formation of Merriam (1919) and Dibblee (1968); (4) the Clews Fanglomerate, (5) Alvord Peak Basalt, and (6) Spanish Canyon Formation of Byers (1960); and (7) the Hector Formation of Woodburne, Tedford, Stevens, and Taylor (1974). Of these various rock units, the writer believes that the name Hector Formation is most appropriately applied to upper Arikareean and Hemingfordian rocks in the study area.

The name Hector Formation was first applied to a fossiliferous sequence of predominantly volcaniclastic sedimentary rocks in the southern Cady Mounains (Woodburne and others, 1974). In its type area, the Hector Formation includes rocks of late early and early middle Miocene (late Arikareean and early Hemingfordian) age. Use of the name Hector Formation in the northern Cady Mountains requires an extension of that nomenclature between two stratal sequences that are geographically isolated from each other. This nomenclatural extension is based partly upon lithologic similarities, and partly upon the original time/space contiguity inferred for the two Miocene sequences in the Cady Mountains area. Accordingly, the term Hector Formation is herein extended away from its type area and into the northern Cady Mountains, even though the type Hector and rocks in the study area only partly overlap in age and even though some lithologic differences exist between the two sequences.

In the writer's view, discrepancies both in age and in lithology that occur occur within the Hector Formation in the Cady Mountains area can be explained, appreciated, and predicted in the context of a single depositional basin. Alluvial/lacustrine environments would be locally developed and would be operating in different ways at different times and at different places within this district-wide basin. Local tectonism and local sedimentation rates would ultimately control the regional evolution and time/space migration of these depositional environments and their rock products. These interpretations and a more extensive justification of the writer's nomenclatural procedure are discussed in the sections of this report dealing with age, correlation, and paleogeographic setting of the Hector Formation in the northern Cady Mountains.

General Features

The Hector Formation in the northern Cady Mountains crops out in a northeast-trending belt that has been exhumed by the downcutting of modern fluvial activity (plate 1). Approximately 1150 ft (395 m) of strata were measured (fig. 4), although about 1250 ft (381 m) of the formation is exposed here. This represents an incomplete sample of the Hector sediments originally deposited in the northern Cady Mountains: the base of the formation is not exposed in the mapped area, several faults of moderate displacement delete portions of the sequence, and the formation is overlain with angular unconformity by upper Tertiary and Quaternary alluvial units.

Lithofacies changes that occur within the sedimentary rocks of the Hector Formation in the northern Cady Mountains partition the unit into two main sequences. These interfinger laterally, and are herein referred to as the distal and proximal sequences of the Hector Formation based on their paleogeographic position with respect to the source area of their sediments (fig. 5). The distal facies (fig. 6) crops out in the northern part of the study area, and constitutes most of the Hector Formation as mapped in the northern Cady Mountains. The proximal sequence (fig. 7) is more restricted in areal distribution, and crops out mainly in the southern part of the mapped area.

Sedimentary rocks in the distal sequence are prevailingly volcaniclastic and fine-grained, and include feldspar-rich, tephra-bearing sandstone and siltstone interbedded with subordinate mudrock, vitric tuff, limestone, and pebble-cobble conglomerate. Sorting is moderate to poor, and the rocks are generally poorly indurated, thick-bedded, and texturally massive.

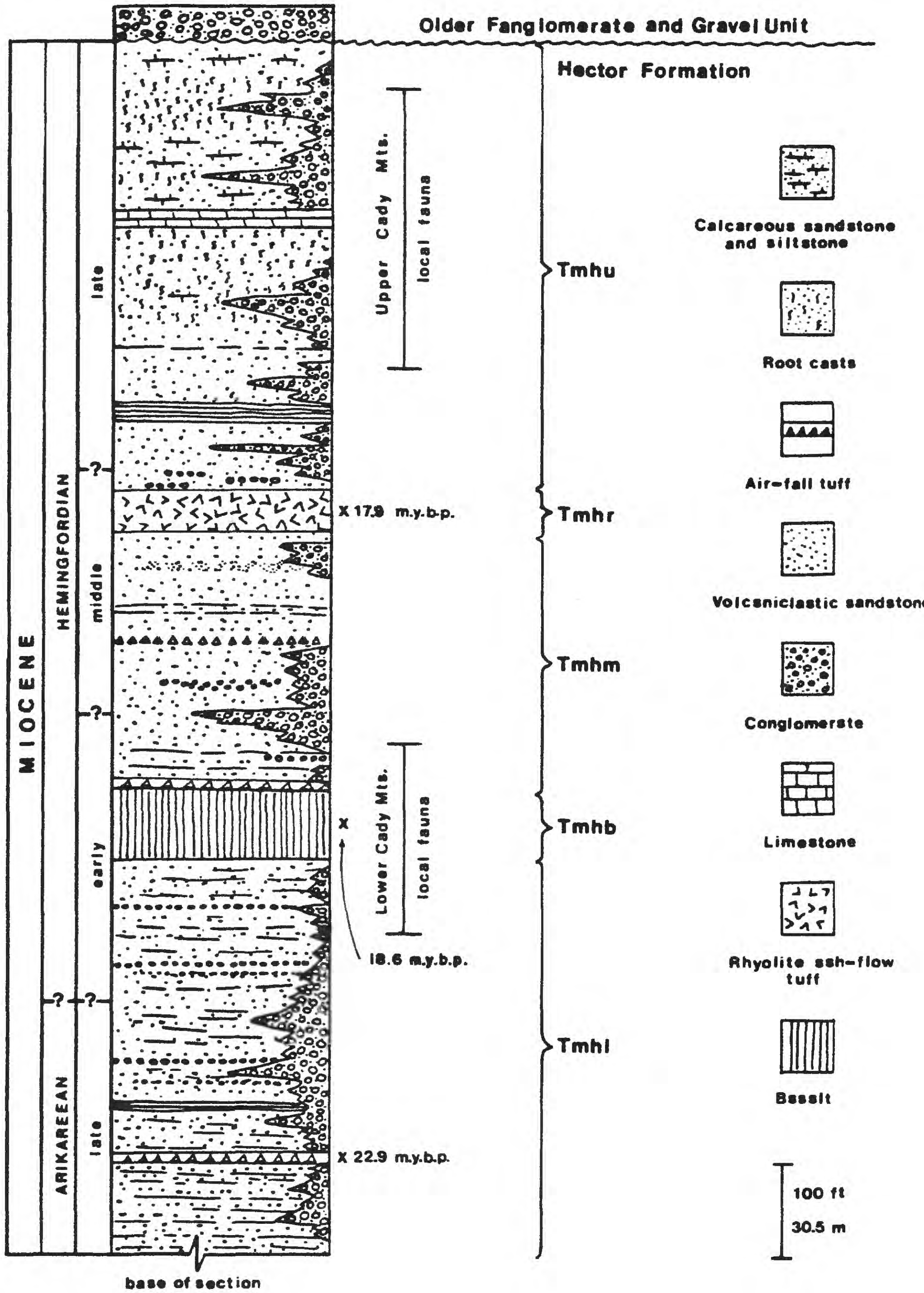

Figure 4.--Generalized columnar section of sedimentary and volcanic rocks exposed in the northern Cady Mountains. These rocks are assigned to the Hector Formation of Woodburne, Tedford, Stevens, and Taylor (1974). The Hector Formation in the study area can be separated into a finer-grained distal facies and a coarser-grainer proximal facies. Lower, middle, and upper sedimentary units, Tmhl, Tmhm, and Tmhu, respectively, are arbitrarily separated by basaltic and rhyolitic marker units, Tmhb and Tmhr.

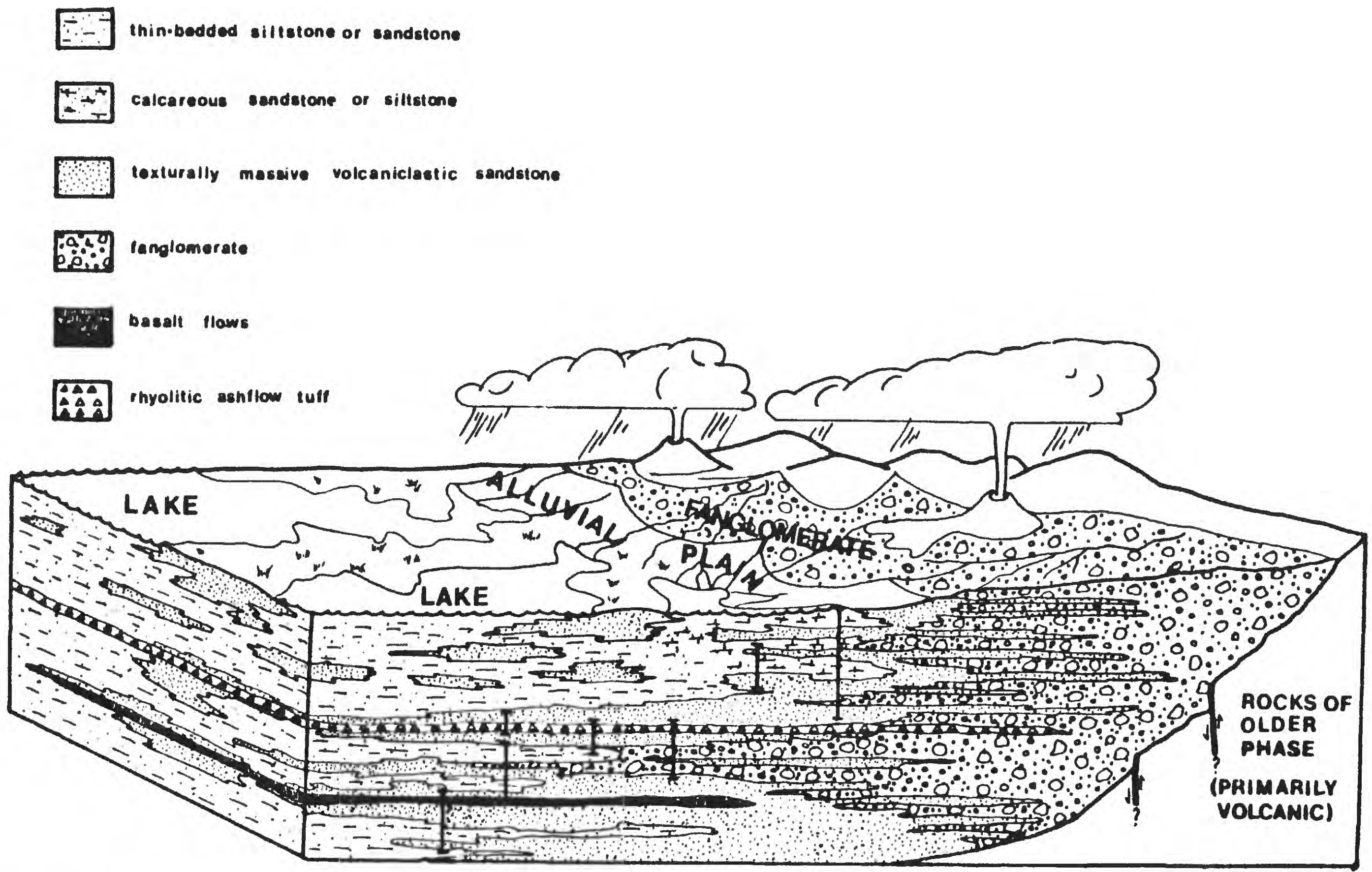

Figure 5.--Block diagram schematically illustrating the paleogeographic setting inferred for the Hector Formation in the northern Cady Mountains. The Hector Formation is interpreted as unconformably overlapping rocks of an older sedimentary/volcanic episode; these served as a local source terrain for epiclastic volcanogenic constituents in the Hector. The proximal facies is interpreted to be a fanglomerate facies; the distal facies is interpreted as a basin-plain facies that accumulated in a variety of alluvial and lacustrine environments. Vertical bars represent the approximate relative paleogeographic positions of stratigraphic sections measured during this study.

Figure 6.--Sandstone and siltstone units in the distal facies of the Hector Formation middle sedimentary unit (Tmhm). Outcrop is well-bedded (see fig. 10). Significant lithologic features include: (A) sandstone that is texturally massive; (B) sandstone having flat-laminated depositional fabrics; (C) channeled base of thick-bedded sandstone bed; and sandstone (D) interbedded with siltstone units (E). Flat lamination probably represents lower-flow-regime deposition of sand on a plane bed with little grain movement. Outcrop of middle sedimentary unit (Tmhm) in northern part of the study area, about 75 ft (23 m) above basalt unit in measured section CADY-IIa.

Figure 7.--Lenticular conglomerate units in the proximal facies of the Hector Formation, upper sedimentary unit (Tmhu). Significant lithologic features include: (A) channeled base of lowest conglomerate bed that scours down into (B) texturally massive sandstone. Note multiple conglomeratic sedimentation units, each inferred to be a separate depositional event. Conglomerate interpreted as catastrophic flood deposits and as channel-filling fluvial deposits. Outcrop in southern part of study area.

The distal sequence of the Hector Formation passes laterally (southward) into the coarser grained proximal sequence. These rocks are characterized by numerous beds of granule, pebble, and cobble conglomerate (fig. 8) bearing predominantly volcanic clasts, but with locally abundant granitic clasts. Feldspathic tephra-bearing sedimentary rocks similar to those in the distal sequence are interbedded with the coarser rocks of the proximal sequence. The facies boundary between the two sequences of the Hector Formation is gradational and is intermittently exposed beneath Quaternary alluvial cover. Thus it is not practical or convenient to map this boundary throughout the study area. For this reason, the distal and proximal sequences are not designated as formal units of the Hector Formation, but are used in an informal way to emphasize distinctive lateral transitions in lithology that can be observed but not easily mapped in the northern Cady Mountains.

Fine-grained volcaniclastic sedimentary rocks in the distal and proximal sequences of the Hector Formation locally exhibit rapid and recurring facies changes both laterally and vertically. Apart from (1) these local variations and (2) the overall southward coarsening discussed above, and (3) two subparallel limestone beds occurring in the uppermost part of the section, no persistent stratigraphic trends or mappable units occur within the sedimentary rocks themselves. Two volcanic marker units do occur, however (figs. 4, 5): a basalt flow (Tmhb) occurs low in the sedimentary sequence, and a welded rhyolitic ash-flow tuff (Tmhr) occurs in the upper part of the sequence. These two marker units were mapped to facilitate structural and stratigraphic control, and they are treated as distinct but informal units within the Hector Formation. The basalt and rhyolite units partition the sedimentary sequence into three parts (fig. 4). These three sedimentary units are not mappable in themselves: they are generally similar in lithology and stratigraphy, and it is difficult to distinguish and map a contact between them where the intervening basalt or rhyolite unit is absent. However, for purposes of convenience in discussing the stratigraphy, biostratigraphy, and structural geology of Miocene rocks in the northern Cady Mountains, these three units are designated as the lower, middle, and upper units of the Hector Formation, respectively.

Physical Stratigraphy of the Sedimentary Rocks

Six major sedimentary lithologies occur in the northern Cady Mountains sequence of the Hector Formation. These rock types are summarized in figure 8. Each of these lithologies occurs in each of the three sedimentary units of the Hector Formation, although their relative frequencies may be different in each unit.

Tephra-bearing, feldspathic and lithic sandstone (fig. 8, A) and siltstone (fig. 8, B).--Volcaniclastic sandstone is the predominant rock type in all three units of the Hector Formation. Volcaniclastic siltstone is the second-most common rock type in all three units of the Hector Formation. Weathered outcrops of these strata are typically very pale green, light green, light-greenish gray, very light gray, pinkish gray, yellowish gray, very pale orange, and white (figs. 9, 10, and 11).

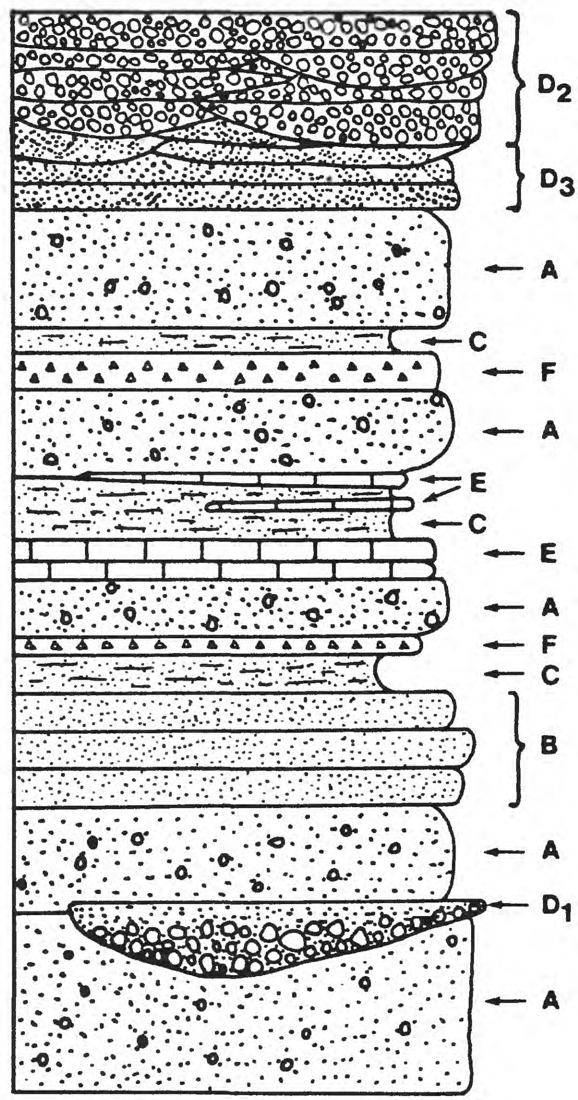

Figure 8.--Diagram schematically illustrating major sedimentary rock types that occur in the Hector Formation. A = thick-, very thick-, and poorly bedded volcaniclastic sandstone; B = volcaniclastic siltstone; C = mudrock; D_1 = texturally massive, matrix-rich lenticular conglomerate (debris-flow deposit); D_2 = lenticular conglomerate having structured depositional fabrics (catastrophic flood deposit and fluvial channel-filling deposit); D_3 = cross-bedded sand-bearing conglomerate and conglomeratic sandstone (fluvial deposit); E = limestone; F = air-fall tuff. No vertical stratigraphic sequence is implied by this diagram.

Figure 9.--Sandstone, siltstone, and mudrock units in the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Significant lithologic features include: (A) poorly bedded and poorly indurated sandstone units interbedded with more resistant, indurated layers of coarser sandstone and granule conglomerate (B). The outcrop as a whole would be poorly bedded were it not for the intermittent occurrence of the latter. Outcrop in the northern part of the study area, about 40 to 80 ft (12 to 24 m) above the basalt unit in measured section CADY-IIa.

Figure 10.--Poorly indurated and poorly bedded sandstone units in the distal facies of the Hector Formation, upper sedimentary unit (Tmhu). Sandstone beds are texturally massive for the most part, and bedding planes are poorly defined. Outcrop in east-central part of the study area, near vertebrate fossil locality M1119 (RV-6630).

Figure 11.--Sandstone units in the distal facies of the Hector Formation, upper sedimentary unit (Tmhu). Significant lithologic features include thick-, very thick-, and poorly bedded sandstone that is texturally massive. Figures are clustered together (A) at vertebrate fossil quarry M1128 (RV-6631) from which the majority of specimens included within the upper Cady Mountains local fauna were collected. View looking northeast at beds occurring between about 230 and 250 ft (70 and 76m) in measured section CADY-IVa. These beds of the distal facies are close to the facies boundary with the proximal facies of the Hector Formation, major tongues of which occur about a quarter of a mile to the south (to the right, out of the photograph).

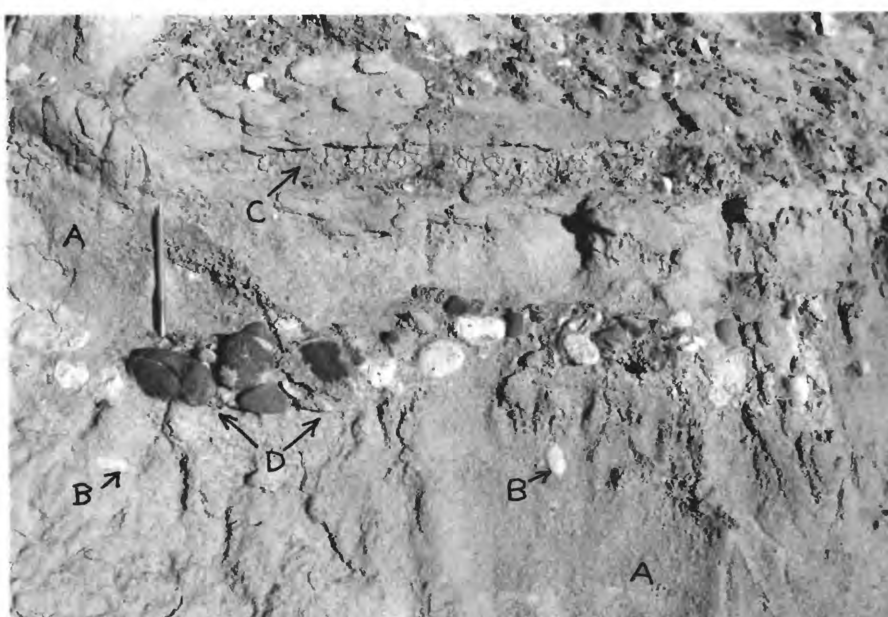

Figure 12.--Sandstone and conglomerate in the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Significant lithologic features include: (A) texturally massive sandstone containing rounded volcanic pebbles (B); (C) lenticular bed of silty sandstone; (D) rounded volcanic pebbles and cobbles in lenticular conglomerate bed. Texturally massive sandstone represents either sediment deposited from flowing water without the production of sedimentary structures, or sediment deposited from low-viscosity sediment flows (contrast with laminated sandstone in fig. 6,B). Lenticular conglomerate bed interpreted to be a small debris flow deposit.

The sandstone beds are generally poorly indurated and relatively nonresistant to weathering, and are poorly exposed as a result. On the whole the sandstone is poorly bedded, and very thin- to thick- and very thick-bedded (figs. 9, 12, 13). Bedding planes usually are weakly defined (figs. 10, 12), and where observed are defined by abrupt changes in grain size (figs. 9, 13, and 14) or by changes in depositional fabric (e.g., massive fabrics passing vertically into structured fabrics; fig. 6). Bedding is more distinct and better defined in some local stratigraphic intervals. The sandstone beds usually are texturally massive and structureless internally (figs. 6A, 12, 15, 16, 17). Traction current plane-bed lamination and cross-lamination occur (figs. 6B, 1B), but these sedimentary structures are not common.

Generally the siltstone beds are better indurated than associated tephra-rich sandstone and claystone beds, and typically crop out as resistant ledges intercalated with these less resistant lithologies. Siltstone units typically are well-bedded, and crop out as thin, medium, and, rarely, thick strata that are parallel-bedded and laterally persistent or that are lenticular. Bedding planes are sharply defined, and are the result of abrupt changes in grain size where siltstone is interbedded with coarser- or finer-grained rocks, or are the result of abrupt changes in framework-grain composition or changes in depositional fabric where several siltstone units are superposed. Most siltstone beds are texturally massive and structureless internally, although some beds display faint plane-bed lamination.

Average grain size in the tephra-rich sandstones ranges from very fine- through very coarse-sand size. Typically, individual beds are moderately to poorly sorted. Poor sorting in many sandstone beds is emphasized by the occurrence of: (1) granule- and pebble-size clasts (figs. 12, 13, 15, 18) or (2) fragmentary and detrital, calcified root casts. Poor sorting in siltstone beds is emphasized by the occurrence of sand-size clasts.

The sandstone and siltstone units are prevailingly volcaniclastic. The framework grains consist predominately of plagioclase, volcanic lithic fragments and tephra. These grains are both epiclastic and pyroclastic in origin, the latter probably including both fresh air-fall volcanic ejecta and reworked volcanic ejecta derived from contemporaneous volcanic centers. The proportions of these three grain types are variable, although confirmed pyroclastic tephra is typically the least abundant of the three. The pyroclastic material is better represented in the siltstone beds than in the sandstone beds. The volcanic lithic fragments are not as abundant in the siltstone lithologies as they are in the coarser-grained sandstone units.

In hand specimen it is difficult to determine the identity of the framework grains because they have only the general appearance of light-colored tuffaceous debris that is vitric in composition. In thin section the plagioclase grains and lithic clasts of intermediate and mafic volcanic rock are easily distinguished, but it is not always easy to discriminate between epiclastic vitric grains and pyroclastic vitric grains. Much of the fabric consists of a murky mat of isotropic material: under low-illumination transmitted light, however, grain boundaries are more apparent, and much of the isotropic debris is seen to consist consist of partially or totally altered vitric fragments. Some of the vitric material consists of fine, texturally massive ash in which relict glass

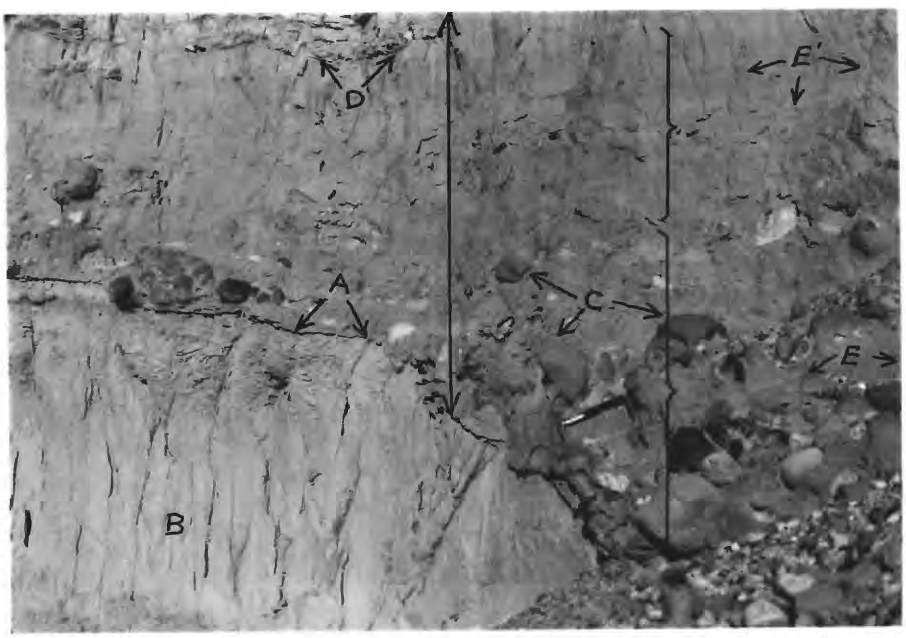

Figure 13.--Conglomerate and sandstone in the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Significant lithologic features include: (A) lower contact of channelized conglomerate that scours down into texturally massive sandstone (B); (C) rounded volcanic cobbles and boulders; (D) scoured upper contact; (E) sand-size volcaniclastic debris that forms matrix in conglomeratic part of bed, but that forms bulk of nonconglomeratic part of the same bed (E'). Entire bed (delimited by vertical arrow) deposited during a single depositional event, here interpreted as a debris flow. Sediment denoted by lower bracket represents a high-viscosity debris flow; sediment denoted by upper bracket interpreted as low-viscosity sediment flow during the same event. This depositional mechanism may account for structureless sandstone in other beds (e.g., B in this figure; Fig. 12,A).

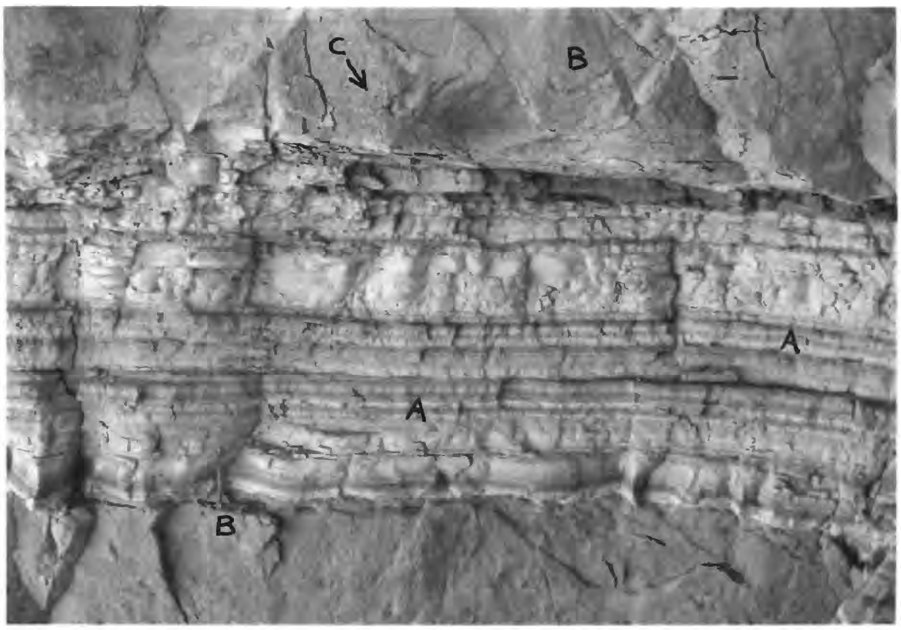

Figure 14.--Mudrock and siltstone units interbedded with sandstone in the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Significant lithologic features include the following: (A) laminated, varve-like depositional fabrics in the mudrock units; (B) texturally massive fabric of sandstone units; and (C) granule- and pebble-size clasts that contribute to poor sorting in the sandstone units. Some siltstone and mudrock layers are ash-rich. The laminated rocks are interpreted as suspension-deposited sediment that accumulated in a standing body of water. Outcrop in the south-central part of the study area, at base of measured section CADY-IIb.

Figure 15.--Conglomerate and sandstone in the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Conglomerate bed is lenticular along strike, and is enclosed by texturally massive pebble-bearing sandstone (A). Note rounded volcanic clasts (B) in conglomerate, and pebble-size clasts (C) in sandstone. Conglomerate is crudely stratified internally, and is interpreted to be of fluvial channel-filling origin. Outcrop is in the central part of the study area.

Figure 16.--Very thick to poorly bedded, texturally massive sandstone in the the distal facies of the Hector Formation, lower sedimentary unit (Tmhl), overlain by basalt unit (Tmhb). Note poorly indurated, easily weathered character of sandstone. Outcrop in the northern part of the study area.

Figure 17.--Basalt unit (Tmhb) overlain by the distal facies of the Hector Formation, middle sedimentary unit (Tmhm). Contrast the prevailingly white, pinkish, and grayish-green aspect of these rocks with the prevailingly greenish aspect of time-correlative rocks 2 miles to the northeast (fig. 9). Basal beds of the middle sedimentary unit consist of biotite vitric air-fall tuff. Laterally, these tuff beds have been reworked into texturally massive and cross-laminated tuffaceous sandstone (fig. 18). The middle sedimentary unit is truncated by ridge-capping older fanglomerate (Qog). View looking northeast, showing rocks in the northwestern part of the study area.

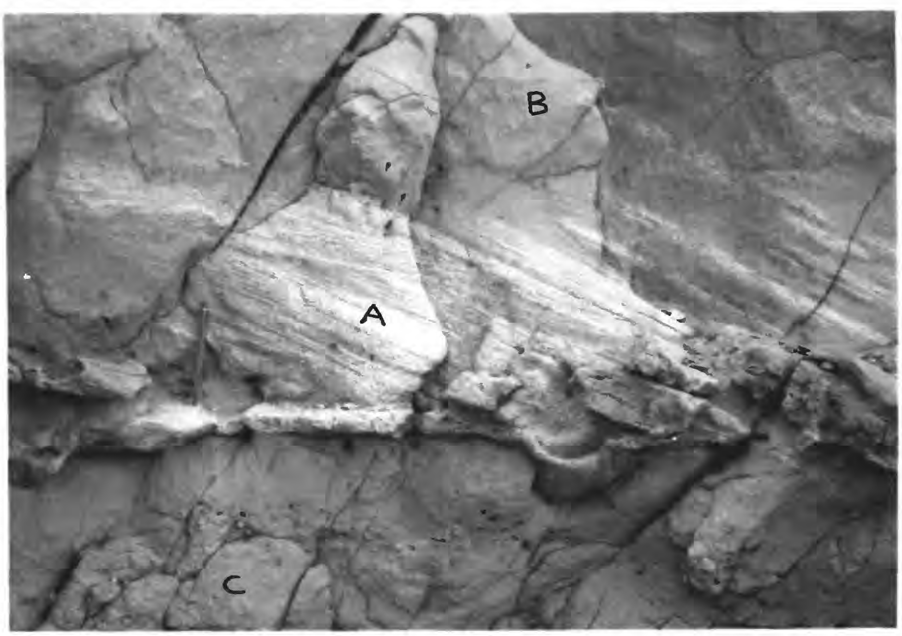

Figure 18.--Distal facies of the Hector Formation. Cross-laminated tuffaceous sandstone (A) and texturally massive tuffaceous sandstone (B) represent reworked equivalents of the air-fall tuff beds that overlie the basalt unit (Tmhb) elsewhere in the study area (e.g., fig. 17). Here, in the south part of the study area, the basalt unit has pinched out, and the tuffaceous sandstone beds (A, B) of the middle sedimentary unit (Tmhm) directly overlie pebble-bearing sandstone (C) of the lower sedimentary unit (Tmhl). The cross-laminated bed (A) is interpreted to be aeolian in origin.

shards are occasionally visible, and these are interpreted as epiclastic tuffaceous grains. Other vitric fragments, described as pumiceous, display a planar fabric of glass with aligned, compressed to ovoid bubble cavities. It is difficult to determine whether these pumiceous grains are epiclastic or whether they represent contemporaneous pyroclastic input. Individual glass shards are present, and these probably are true pyroclastic constituents.

Sand-, granule- and pebble-size clasts of fine-grained intermediate and mafic volcanic rock ocur as outsize grains that are randomly distributed within the grain-supported fabric of some siltstone and sandstone beds (figs. 12, 15, 18). Subordinate framework grains include sanidine; volcanic quartz that is limpid and commonly displays bipyramidal crystal morphologies; oxyhornblende; plutonic quartz having undulatory extinction and trains of vacuoles and inclusions; orthoclase; biotite; epidote and silt-, sand-, granule- and pebble-size granitic clasts. Locally, the granitic constituents and clasts are abundant, although few truly arkosic sandstone beds were observed. Detrital and *in situ* fossil root casts are abundant in some siltstone beds along with calcareous nodules and caliche stringers. Framework grains are angular to rounded.

Volcaniclastic siltstone and sandstone beds in the northern Cady Mountains sequence of the Hector Formation exhibit lateral stratigraphic trends in color, grain size, and frequence of occurrence. Although these trends are neither abrupt enough nor dramatic enough to clearly demarcate mappable rock units, they nevertheless can be observed along traverses through the mapped area. (1) Siltstone and sandstone units cropping out in the northern part of the distal facies of the Hector Formation are generally light green, pale green, light greenish gray, and very light gray in color (figs. 6, 9). As the distal facies is traced southward and southwestward, the siltstone and sandstone units lose their green color and exhibit prevailingly very light-gray, white, pinkish-gray, yellowish-gray and very pale-orange hues (fig. 17). (2) As the distal facies of the Hector is traced southward, the volcaniclastic sandstone beds become more numerous at the expense of claystone, mudstone, and siltstone beds. (3) Sandstone units in the Hector Formation are on the whole coarser-grained in the southern part of the study area than equivalent units in northernmost areas. The southward elimination of siltstone units and the trend in sandstone grain size form part of the basis for recognition of distal and proximal facies of the Hector Formation.

No persistent vertical trends in siltstone and sandstone lithology occur in the northern Cady Mountains sequence of the Hector Formation.

Mudrock (fig. 8, C).--In this report, a mudrock is considered to be a sedimentary rock in which the clay-size fraction predominates over the silt-size fraction. Tephra-rich mudrock is locally abundant in the distal sequence of the Hector Formation (fig. 14) but does not constitute an important component in the sequence. Weathered outcrops of the mudrock are typically very pale green, light-greenish gray, very light gray, bluish white, and white colored. The rocks are generally poorly to moderately indurated and relatively nonresistant to weathering, and crop out poorly as a result. The mudrock usually crops out in thick and very thick units that are either texturally massive and structureless, or in units that are faintly to strongly flat-laminated (fig. 14). In some outcrops, the laminations are crenulated and deformed, a feature attributed to deformation during loading and dewatering of the fine-grained sediment. Fissility is rarely developed.

Individual mudrock units are poorly sorted to well-sorted. Detrital constituents are mainly fine vitric ash and clay, with much of the vitric material having devitrified to clay. Mudrock in the northwestern portion of the distal sequence contains discontinuous and irregular seams of gypsum. Detrital calcified fossil root casts are present in some mudrock units.

The mudrock units in the northern Cady Mountains sequence of the Hector formation are virtually eliminated from the sequence in the southernmost part of the mapped area. These rocks are most abundant in the distal facies of the Formation, and are replaced by coarser-grained units as the distal facies is traced southward. No persistent vertical trends in mudrock stratigraphy occur in the northern Cady Mountains sequence of the Hector Formation.

Lenticular conglomerate and sand-bearing conglomerate (figs. 8, D_1, D_2, D_3).--Beds of pebble, cobble, and boulder conglomerate and sand-bearing conglomerate occur commonly in the proximal sequence of the Hector Formation (figs. 7, 19), and less commonly in the distal sequence (figs. 12, 13, 15). The conglomeratic units are medium-, thick-, and, rarely, very thick-bedded. They are generally well indurated and fairly resistant to weathering, and crop out as resistant ledges intercalated between less resistant outcrops of associated sandstone, siltstone, and claystone. The conglomerate beds are lenticular and are interpreted as channel fillings: some thin and medium beds form lens-like bodies only a few meters in length (figs. 12, 13, 15), whereas thicker conglomerate bodies are more nearly parallel-bedded and their lenticular geometry can only be discerned when they are traced several tens of meters along strike (figs. 7, 19).

Clasts in the conglomerate beds range from granule to boulder in size, and sorting in any individual conglomerate typically is poor. Clast types are dominated by fine-grained, porphyritic volcanic rocks of intermediate and mafic composition, but include various kinds of granitoid and metamorphic rocks. In most conglomerate beds the clasts are rounded, although in a few beds the clasts are angular and subangular.

Three main types of conglomerate occur in the northern Cady Mountains sequence of the Hector Formation:

(1) Some conglomerate beds are typically small lenticular bodies that are usually texturally massive and that lens out within a few meters (fig. 8, D_1; figs. 12, 13). These beds have a poorly sorted matrix of sand- and granule-size tephra that occurs between the framework clasts and that usually predominates in the upper part of the conglomerate bodies (fig. 13). These beds are interpreted to be sediment-gravity flows (mud flows and debris flows).

(2) Most conglomerate beds are better-sorted bodies in which a tephrarich matrix does not occur, or is only weakly developed (figs. 8, D_2; figs. 7, 19, 16). As described above, these beds may be locally lenticular, or may be

Figure 19.--Conglomerate and sandstone in the proximal facies of the Hector Formation, upper sedimentary unit (Tmhu). Note crude internal stratification of conglomerate, here interpreted to be of catastrophic flood origin. Outcrop in the southern part of the study area.

Figure 20.--(A) Rhyolitic welded ash-flow tuff unit of the Hector Formation (Tmhr). White air-fall tuff beds overlying the basalt unit crop out in the lower left corner of the photograph (B). The distal facies of the upper sedimentary unit of the Hector Formation (Tmhu) crops out in the center of the photograph (C). View of the east-central part of the study area, looking southeast.

locally parallel-bedded but grossly lenticular. These bodies commonly have lower bedding surfaces that are irregular and scoured (fig. 7) and they display a wide range of depositional fabrics including massive texture, crudely developed graded bedding, crudely developed plane-bed lamination and irregular lamination (figs. 7, 19), pebble imbrication, and local channel-development and scour-and-fill internally within the main conglomerate body. These sand-and granule-bearing conglomerate beds are interpreted to be catastrophic flood deposits and channel-filling deposits.

(3) Many sand-bearing pebble conglomerate beds and conglomeratic pebbly sandstone beds are cross-laminated (figs. 8, D_3; fig. 15). These bodies locally exhibit a lenticular or sheet-like geometry, and a variety of tabular, planar, and trough cross-laminae. These beds are interpreted to be alluvial deposits.

The matrix-bearing conglomerate (sediment flows, D_1) occurs intermittently throughout the distal sequence of the Hector Formation, but was not observed in the proximal sequence. Matrix-poor conglomerate, sandy conglomerate, and conglomeratic sandstone (flood deposits and fluvial deposits, D_2 and D_3) occur sparingly throughout the distal sequence but are common in the proximal sequence of the Hector Formation, and the abundance of these beds in the southern part of the mapped area forms part of the basis for distinguishing the proximal facies of the Formation.

Limestone (fig. 8, E) and calcareous nodules.--Beds of fine-grained limestone occur intermittently in the upper sedimentary unit of the Hector Formation, and occur rarely in the middle and lower sedimentary units. Weathered outcrops of these strata are pinkish gray, very light gray, bluish white, and white. The rocks are well indurated, and crop out as resistant ledges intercalated between less resistant sandstone, claystone, and mudrock. The limestone units are well-bedded, and occur as thin, medium, and thick strata that locally are lenticular or that are parallel-bedded and laterally persistent. Bedding planes are sharply defined, and are marked both by abrupt changes in grain size and by changes in composition between the carbonate beds and superposed noncarbonate strata. Most limestone beds are texturally massive and structureless internally.

The limestone consists of very fine-grained, texturally massive micrite. Randomly distributed allochems supported by the lime-mud matrix include vitric and lithic fragments, quartz, feldspar, biotite, gastropods, ostracodes, and fossil bone fragments.

Irregular and lenticular calcareous nodules and crusts occur intermittently throughout the distal and proximal facies of the Hector Formation. These are fine-grained and texturally massive, and are associated with most of the major sedimentary rock types. These probably represent caliche nodules and stringers.

The limestone units occur primarily in the upper unit of the Hector Formation, and they are confined to the distal facies of the formation. Some of these limestone beds are quite persistent laterally: two units in particular are widespread and easily recognized, and these are shown on the geologic map (plate 1). These two beds were used to correlate between measured sections CADY-IVa and CADY-IVb (plate 4). The limestone beds increase in number toward the upper part of the upper Hector unit (Tmhu), until they ultimately become one of the dominant rock types in this part of the sequence.

Air-fall tuff (fig. 8, F).--White, very fine-grained biotite-bearing vitric air-fall tuff beds occur infrequently throughout the northern Cady Mountains sequence of the Hector Formation. The weathered surface of these tuff beds is typically friable. These units vary in thickness from less than one inch (2.54 cm) to greater than 5 ft (1.5 m). The thickest of the air-fall tuff beds overlies the basalt unit in the northern and central parts of the study area (fig. 17) where it ranges from less than one to greater than 5 ft (<0.3 to >1.5 m) thick. In the southern part of the mapped area, this bed grades into a cross-laminated tuffaceous sandstone that probably was deposited by wind (fig. 18).

An air-fall mode of deposition for the tuffs is suggested by the following evidence: (1) the upper and lower contacts of the tuff beds are sharp; (2) the tuff units are laterally extensive; (3) the tuffs are very well sorted and consistently very fine-grained; (4) the glass shards and biotite flakes show no evidence of reworking or of transport by fluvial mechanisms (e.g., rounding); and (5) the tuff beds have a massive texture. Moreover, the tuff beds show no evidence which would definitely suggest deposition in a lacustrine environment, for example: (a) graded bedding; or (b) inclusion of foreign materials (e.g., pebbles, invertebrate fossils, plant debris).

Age.--One of the air-fall tuff beds, (D.E. Savage, 1970, locality 7014) located at the base of measured section CADY I (plate 2), yielded a K/Ar radiometric age of 22.9 ± 0.4 m.y.b.p. (plagioclase; D.E. Savage and G.H. Curtis, personal communication, 1977 and 1980; DES 7014, from NE1/2NE1/4, sec. 11, T. 10 N., R. 6 E., S.B.M.). This biotite-bearing vitric air-fall tuff occurs approximately 110 feet (30.5 m) above the base of the Hector Formation as exposed in the northern Cady Mountains.

Petrography and Stratigraphy of the Basalt Unit

A basalt flow that occurs widely throughout the study area is designated as a distinct but informal unit of the Hector Formation because of its ease of recognition and mappability as a marker unit (figs. 16, 17). This flow is shown as Tertiary basalt (Tsb) by Dibblee and Bassett (1966b). The basalt unit conformably intervenes between the lower and middle sedimentary rock units of the Hector Formation (fig. 4). The conformable nature of the contacts of the basalt with overlying and underlying strata is demonstrated in the southern part of the mapped area. There, the basalt pinches out between parallelbedded strata which show no evidence (e.g., channeling, development of a soil horizon, etc.) indicative of a paraconformity (fig. 18; plate 1). Although none were documented, local diastems may be present where pre-basalt fluvial activity exposed older rocks to the basalt flow.

The contact between the basalt flow and underlying pebble conglomerate and sandstone of the lower unit locally displays flow striations and/or grooves. The immediately underlying conglomeratic sandstone unit is colored bright pink to red. As this unit occurs only beneath the basalt, its reddish color is interpreted to be the result of baking produced as the basalt flow encroached over the sediment. Except for one portion of its outcrop belt, the irregular and gently-rolling upper surface of the basalt is overlain throughout the study area by a white, biotite-bearing vitric air-fall tuff of the Hector middle sedimentary unit (fig. 17). In the southern part of the mapped area, however, the white tuff grades laterally into reworked tuffaceous sediment, and the basalt here is overlain by a sequence from 2 to 30 ft- (<1 to 8 m-) thick of cross-laminated sandstone (fig. 18). The cross-laminae are small to large in scale (<15 cm to 73 m), and are inclined at relatively high angles. Because of these features (and the proximal position of outcrops), this sequence is interpreted to have been deposited by wind.

The basalt flow varies considerably in thickness within the study area. A thickness of 70 ft (21 m) was measured in section CADY-I (plate 2) near the west end of the study area, but the flow thins to the east and to the south, where, as noted above, it ultimately pinches out between underlying and overlying sedimentary rocks (plate 1).

The basalt is grayish black on fresh surfaces. A dark-reddish-brown iron-oxide stain coats the lower few meters of the unit, but the rest of the flow weathers to a greenish-black color.

Texturally, the unit is a hypocrystalline to holocrystalline, aphanitic to fine-grained microcrystalline, vesicular to scoriaceous, subophitic and rarely microporphyritic basalt. The scoriaceous texture is generally confined to the lower few meters of the unit. Amygdaloidal fillings consist of calcite, quartz, mica, and clinoptilolite. Compositionally, the unit is an alkaliolivine basalt with the following constituents: plagioclase (55 to 60%, An_{50-55}); pale brown augite (10 to 15%); ilmenite (5 to 10%); olivine altered to dark reddish brown iddingsite, hematite, and other iron oxides (5 to 10%); chlorite (1%) chlorophaeite (?) (<1%); and glassy material altered to yellow-orange smectite (0 to 5%). The anhedral to subhedral augite occurs interstitially between the subhedral plagioclase laths.

Age.--An average potassium/argon radiometric age of 18.6 ± 0.2 m.y.b.p. was obtained from two whole rock samples of the basalt (M. L. Silberman, personal communication, 1979; STM 7612, from the NW1/4 SW1/4, sec. 31, T. 11 N., R. 7 E.; and STM 7504, from the NE1/4 NW1/4,sec. 12, T. 10 N., R. 6 E., S.B.M.).

Petrography and Stratigraphy of the Rhyolite Ash-flow Tuff Unit

A rhyolitic ash-flow tuff that occurs widely throughout the study area is designated as a distinct but informal unit of the Hector Formation because of its ease of recognition and mappability as a marker unit (fig. 20). This ash-flow is shown as Tertiary intrusive rhyolitic felsite (Trf) by Dibblee and Bassett (1966b, p. 2). The rhyolitic tuff conformably intervenes between the middle and upper sedimentary rock units of the Hector Formation (fig. 4). The ignimbrite appears to vary in thickness within the mapped area, although the entire thickness of the unit is rarely exposed. It is about 45 ft (14 m) thick at a prominent exposure in the northern part of the study area.

The ash-flow is commonly welded, especially in its lower part, although the degree of welding varies both laterally and vertically. The unit ranges in color from moderate pink, grayish pink, and grayish-orange pink (fig. 20) through red purple, grayish purple, and pale purple. The latter three colors are characterisitic of welded portions of the unit.

The ash-flow tuff is hypocrystalline and vitrophyric, and is rhyolitic in composition. A dense cryptocrystalline groundmass of pale brown glass and dust (50 to 60%) surrounds phenocrysts of subhedral biotite (10%), anhedral quartz (10 to 15%), anhedral sanidine (15 to 20%), euhedral hornblende (2 to 5%), anhedral sodic plagioclase (2%, An_{15-25}), and subhedral magnetite (2%). The phenocrysts of quartz and feldspar commonly show embayed margins. The ash-flow tuff contains minor accidental lithic fragments of volcanic and granitic origin. The volcanic fragments are intermediate to mafic in composition. The granitic fragments consist of perthitic intergrowths of sodic plagioclase, quartz, and potassium feldspar. Welded portions of the ash-flow sheet exhibit a eutaxitic fabric of flattened and aligned pumice fragments, broken glass shards, and elongate lithic fragments.

Age.--A potassium/argon radiometric age of 17.9 $\pm$ 0.3 m.y.b.p. was obtained from the rhyolitic ash-flow tuff (sanidine; D.E. Savage and G.H. Curtiss, personal communication, 1977 and 1980; DES 7013, from the SW1/4SE1/4, sec. 12, T. 10 N., R. 6 E. S.B.M.).

Paleogeographic Setting and Depositional History

As summarized in the discussion on regional geologic setting, the northern Cady Mountains is just one of a series of localities in the central Mojave Desert where Miocene sediments accumulated as thick basin-fill sequences. These basins were located adjacent to higher standing terrains that served as source areas for sediment in the various basin-fill sequences. Source terrains were of three types: (1) older volcanic/sedimentary terrains that provided epiclastic constituents; (2) local volcanic centers that provided contemporaneous pyroclastic constituents; and (3) older granitic terrains that were locally exposed and that provided fresh arkosic debris. Within this generalized paleogeographic setting, Miocene sediments in the northern Cady Mountains accumulated in a variety of depositional environments, and were transported and deposited by a variety of sedimentary mechanisms.

Paleogeographic setting.--Miocene rocks in the northern Cady Mountains acumulated in a subsiding and aggrading trough flanked by higher standing terrains that furnished the sediment-fill for this trough. Sedimentologic evidence presented above indicates that these sediments accumulated mainly by catastrophic sheet-flood, sediment-gravity-flow and fluvial mechanisms. Finegrained mudrock and limestone were formed under lacustrine conditions. The depostional basin is envisioned as a relatively broad, gently inclined alluvial plain that passed laterally upslope into the toes of alluival fans, and that interfingered downslope with a basin-plain complex of ephemeral ponds and marshes that fringed a semi-permanent body of standing water. This paleogeographic setting is depicted in figure 5.

The distal facies of the Hector Formation in the northern Cady Mountains largely records sedimentation on the gently inclined alluvial plain. Here, sand and silt were deposited by catastrophic sheet-wash processes and by normal fluvial processes within what was probably a network of anastomosing drainages that formed a distal braided flood plain. Here also, sand and silt were transported by sediment-water slurries or fine-grained sheeted mud flows, and many sediments deposited on the alluvial plain may have accumulated by these sediment-gravity flow mechanisms. Coarser mud flows and debris flows locally deposited lenticular conglomerate, and high energy flowing water deposited cross-laminated and flat-laminated fluvial conglomerate and conglmeratic sandstone in localized areas.

The distal edge of the Hector Formation in the mapped area includes beds that formed in a zone of ephemeral ponds and marshes. These occur in all three sedimentary rocks units of the Formation, but are best developed in the upper sedimentary unit (Tmhu). Some intervals of mudrock and limestone represent tongues of the main semi-permanent standing body of water, and a significant incursion of this lake body is represented by abundant mudrock and limestone units in the upper sedimentary rock unit (Tmhu, fig. 6). While most of the Hector Formation was being deposited in the northern Cady Mountains, however, the main body of standing water was located beyond the mapped area. The abundance of limestone in the upper unit suggests the possibility that as the basin filled the lake became larger and more extensive geographically.

The distal facies of the Hector Formation in the northern Cady Mountains passes laterally into coarser-grained sedimentary rocks assigned to the proximal facies of the Formation. These rocks represent sand through boulder-size sediment deposited under high energy conditions in a variety of alluvial environments. Lenticular conglomerate beds represent coarse channel-fill deposits formed by catastrophic floods. Cross-laminated sand-bearing conglomerate and conglomeratic sand represent proximal braided-stream deposits, while texturally-massive sand bodies represent both sheet-wash deposits and sheeted mud flows. As shown in figure 5, these interpreted depositional environments in the proximal sequence of the Hector Formation are considered to be distal portions of alluvial fans, the toes of which periodically prograded across the upland edge of the alluvial plain.

The Miocene depositional trough in the northern Cady Mountains is interpreted to have had an overall elongate geometry, with the localized basin axis trending generally east-west. As shown in figure 5, a higher standing provenance terrain was situated generally south of the study area, although embayments and irregularities in the basin margin probably created local southeastern highland source areas. A southern source for Miocene sediments in the northern Cady Mountains and a southward-rising paleoslope are suggested by several features: (1) the coarsening in grain size observed as the distal facies is traced southward into the proximal facies of the Hector Formation; (2) increasing frequency of lenticular pebble and cobble conglomerate in the southern part of the mapped area; (3) paleocurrent indicators (cobble imbrication and cross-bedding) that suggest northward-flowing streams and flood surges; and (4) the southward pinch-out of the basalt unit (Tmhb), probably created by the basalt flow lapping up onto the higher standing southern flanks of the basin.

Several different types of source terrain provided sediment to the northern Cady Mountains sequence of the Hector Formation: (1) an older volcanic/sedimentary terrain, (2) local volcanic centers that were active during deposition of the Hector Formation, and (3) older terrains that provided arkosic and granitic debris.

An older (pre-Hector) volcanic source terrain is indicated by two features: (1) the volcaniclastic sandstone and siltstone units in the Hector Formation have framework grains that are dominated by volcanic lithic fragments, and (2) the pebbles, cobbles, and boulders in the conglomeratic units are dominated by clasts of intermediate and mafic volcanic rocks. Pebbles of volcanic rocks also occur as outsize clasts in the sandstone and siltstone units. Most, if not all, of these volcanic constituents are interpreted to be epiclastic materials derived from a pre-Hector volcanic terrain. This interpretation is based mainly on the rounded character of both the sand-size constituents and the pebbles, cobbles, and boulders - rounding which implies a more extensive history of weathering, erosion, and transportation than would be achieved if all these constituents were pyroclastic or accessory and were erupted contemporaneous with sedimentation.

The older volcanic source terrain probably was located near to the Hector depositional basin, judging from the size of some of the clasts and from the poor sorting of the conglomeratic and sandstone units in the Hector Formation, and judging from the rapid coarsening that the Formation as a whole displays as it is traced to the southeast, south, and southwest. A likely candidate for this pre-Hector volcanic terrain is an extensive series of mafic, intermediate, and silicic lava flows, pyroclastic rocks, and conglomeratic sedimentary rocks bearing volcanic and granitic clasts that occur immediately south and southwest of the study area. These units occur in Tps. 9 and 10 N., R. 6 E. of the Cady Mountains quadrangle, and are mapped as Tb, Tbb, Tfb, Ta, Tab, Tt, Tfa, Tg, Tss, and Tl by Dibblee and Bassett (1966b). As discussed earlier in this report, the Hector Formation in the northern Cady Mountains is believed to unconformably overlie these older rocks and to depositionally overlap them. It is reasonable to assume that these older volcanic/sedimentary rocks provided a locally available source for epiclastic constituents in the Hector Formation as it lapped onto the pre-Hector erosional surface.

Intermittent volcanism occurred contemporaneous with deposition of sedimentary rocks in the northern Cady Mountains sequence of the Hector Formation, as indicated by two features: (1) volcanic rocks are intercalated with the sedimentary rocks, including air-fall tuff beds that occur intermittently throughout the sedimentary sequence and including a basalt flow and rhyolitic ash-flow tuff that occur in the middle of the sequence. (2) Pyroclastic tephra is a minor constituent of some volcaniclastic sandstone and siltstone units in the Hector Formation. Thus, contemporaneous volcanic activity contributed to the Miocene sediment-fill in the northern Cady Mountains, even though the succession is mainly an alluvial/lacustrine sequence composed primarily of epiclastic rather than of pyroclastic volcanic constituents.

Granite-derived constituents are locally abundant in the northern Cady Mountain sequence of the Hector Formation. These include uncommon orthoclase and microcline feldspar and plutonic quartz in the sandstone units, outsize granitoid clasts in the sandstone units, and granitoid pebbles, cobbles, and boulders in some of the conglomerate units. Some of the sand-size arkosic constituents and some of the coarser pebbles are subangular and fresh-appearing, and these may represent first-cycle arkosic debris derived from local outcrops of granitoid basement complex. However, most of the observed granite-derived clasts are relatively well rounded, suggesting a second-cycle origin. Dibblee and Bassett (1966b) describe conglomeratic units bearing granitoid cobbles in the pre-Hector volcanic/sedimentary sequence, and it is likely that the rounded granitoid clasts in the Hector Formation were recycled from these older sedimentary rocks. In any event, granite-derived debris is not a significant component of sedimentary rocks in the northern Cody Mountains sequence of the Hector Formation.

In summary, the northern Cady Mountains sequence of the Hector Formation represents an alluvial/lacustrine sequence that accumulated in a paleogeographic setting that incorporated (1) a basin-plain complex of lakes, ponds, and marshes; (2) a gently-inclined alluvial plain complex; and (3) a distal alluvial fan complex. Sediments deposited in these enivronments lapped onto an erosional surface that was developed on an older volcanic sedimentary terrain. This terrain provided epiclastic volcanic and granitic constituents to the Hector Formation. Granitoid basement outcrops may have been locally exposed. Intermittent volcanism of basaltic and rhyolitic composition accompanied deposition of the alluvial/lacustrine sediments.

<u>Depositional history</u>.--<u>Sandstone and siltstone deposited by streams, by catastrophic sheet floods, and by sediment-gravity flows</u>: Some of the poorly sorted, volcaniclastic sandstone and siltstone units in the Hector Formation clearly were deposited by fluvial processes. These beds are lenticular, and they display flat-lamination and cross-lamination indicative of traction-current deposition from flowing water (fig. 6B).

Most volcaniclastic, granule- and pebble-bearing sandstone and siltstone units in the Hector Formation, however, dispay enigmatic characteristics which make it difficult to interpret their depositional history. These characteristics include: (a) the absence of internal sedimentary structures (massive texture; figs. 6A, 10, 12A, 13B, 14B); (b) the sheet-like rather than lenticular geometry of many individual sediment bodies (fig. 9); (c) particle sorting that is generally poor (figs. 12B, 14C, 15C, 18C); and (d) bedding that typically is poorly defined (figs. 9, 10, 17).

The most puzzling aspect of these rocks is their massive fabric: the sediments were deposited largely without the formation of sedimentary structures. The actual mechanism of their deposition is not known, but two possible models are suggested for the origin of these sediment bodies: (1) they may have been deposited rapidly from sediment-choked flowing water (torrential floods), or (2) they may have been deposited from sediment gravity flows. It is difficult to ascribe either origin to any given bed on the basis of its lithologic features.

If many of these texturally massive sandstone and siltstone units were actually deposited from flowing water, then they must represent sediment deposited under hydraulic conditions or under sediment-load conditions that did not permit the formation of these sedimentary bed forms that are diagnostic of deposition from flowing water (e.g., plane bed lamination, ripple and dune lamination, scour-and-fill, and so forth). Such conditions might be achieved during catastrophic storm floods when sediment-choked sheet wash spreads over flat or gently inclined surfaces. The poorly sorted bed-load sediment entrained by these sheet floods would not be deposited until the velocity of the floods began to wane. At this point pebble- and granule-bearing sand and silt would be deposited so quickly from waning flood waters that the orderly development of dune forms, ripple forms, and plane-bed forms within the poorly sorted sediment would be prevented. A structureless sediment body would result. Better-sorted siltstone units may represent suspended-load material deposited from dwindling sheet floods. On subaerial surfaces, dumping of poorly-sorted sediment from torrential sheet wash may be initiated by changes in gradient between alluvial-slope and alluvial plain settings; alternatively, torrential sediment accumulation could be triggered when sheet-wash floods entered standing bodies of water which would slow their velocity and intiate sediment dumping. In any case, bodies of texturally massive sediment are interpreted to be the products of a single depositional event (e.g., figs. 6A, 12A, 13B, 14B).

The second depositional model suggests that the texturally massive sediment was deposited as sheeted sediment-gravity flows. These water-saturated slurries are thought to have been generated by torrential rains associated with eruption clouds vented from nearby volcanic centers. In this model, epiclastic and pyroclastic debris mantling the terrains adjacent to volcanic vents and cinder cones would become water saturated during period of torrential rainfall. Water-saturated ash, lapilli, and chemically and mechanically weathered epiclastic material would become unstable on even gentle slopes, and under the influence of gravity would begin to move downslope as soupy mixtures of water and sediment. Concentrated in gullies and draws, the slurries would gather momentum and begin to behave as fine-grained, low-viscosity mud flows and debris flows. These fine-grained flows would have sufficient shear strength to pick up and to transport outsize clasts that would otherwise be out of hydraulic equilibrium with the prevailingly sand- and silt-size material constituting the bulk of the sediment load. Epiclastic granitic debris and volcanic pebbles and cobbles would thus become incorporated into the sediment-gravity flows during their transport history. An important feature of these sediment-water slurries is that they would have considerably less shear strength than typical dense, viscous mud flows and debris flows: they would thus be able to travel at great velocity where channelized, and would be able to fan out and form laterally persistent, sheet-like sediment lobes when they issued out of gullies and canyons.

A particularly good example of this inferred depositional process is illustrated in figure 13. Here, a conglomerate body interpreted to be a debris flow has channeled down into sandstone. The conglomeratic part of this debris flow (fig. 13, lower bracket) passes transitionally upward into texturally-massive sandstone (fig. 13, upper bracket), and the sandstone is truncated by a sharp upper contact (fig. 13, D). Both the conglomeratic and the nonconglomeratic portions of this entire bed (delimited by vertical arrow) are interpreted to have formed by sediment-gravity-flow mechanisms. The texturally massive sandstone portion of the bed is interpreted to be a low-viscosity phase of the same gravity-flow event that was viscous enough in its early phase to transport cobbles and boulders. This inferred mechanism may account for the origin of other texturally massive sandstone units that were not necessarily associated with a high-viscosity mud-flow phase (e.g., B in fig. 13; figs. 10, 11, 12B, 14B).

The two inferred depositional mechanisms discussed above are probably end members of a continuous spectrum of depositional processes that ranges from debris-choked running water to low-viscosity sediment-water slurries. The boundary between one depositional mechanism and the other is diffuse, and it is possible that both depositional mechanisms were operating when the volcaniclastic sedimentary sequence in the Hector Formation was deposited.

Conglomerate and sand-bearing conglomerate deposited by fluvial mechanisms: Pebble, cobble, and boulder conglomerate beds having lenticular geometries are interpreted as high-energy fluvial deposits (figs. 7, 15, 19). The conglomerate units are well stratified internally (fig. 7), with each layer interpreted to be a separate sedimentation unit. The layers themselves are generally structureless, although some show pebble imbrication and others show crude plane-bed lamination (fig. 19). These beds are all considered to be coarse channel-filling gravels deposited during catastrophic floods (figs. 7, 15, 19). Some beds of sand-bearing granule and pebble conglomerate and some beds of conglomeratic sandstone are cross laminated. The cross laminae occur as tabular and planar sets and cosets that are interpreted as foreset lamination associated with transverse and longitudinal bars. These bars formed in a braided-stream system and represent ordinary, noncatastrophic fluvial processes. Trough cross-lamination also occurs, and probably represents scour-andfill channeling or less likely, large lunate or cuspate dune forms.

Matrix-bearing conglomerate deposited by debris flow mechanisms: Lenticular beds of pebble, cobble, and boulder conglomerate having a tuffaceous matrix are interpreted as debris flows and mud flows (figs. 12 and 13). Deposition from gravity flows is suggested by their poor sorting and prevailingly massive, structureless texture. Crudely graded fabrics also occur, and these may reflect a transition between debris-flow processes and turbid-flow processes.

Clay, silt and calcium carbonate of lacustrine origin: Mudrock and some siltstone in the northern Cady Mountains sequence of the Hector Formation are interpreted to be the products of suspension deposition from a standing body of water. Although fine-grained sediment conceivably could have settled from overbank flood waters spread over the flood plain of a major river system, this origin for the mudrocks was discounted because there is no evidence for the diagnostic series of depositional environments associated with fluvial flood plains (e.g., cross-laminated point bar sands; flat-laminated channel sands and channel-lag conglomerate; levee and crevasse-splay sand, silt, and clay; and the characteristic iterative sequences of fining-upward stratigraphic cycles that typify fluvial-meander-belt and flood-plain systems). Instead, suspension deposition of fine sediment is interpreted to have occurred in a semipermanent, standing body of water that was flanked by ephemeral ponds and marshes.

In a review article discussing criteria for the recognition of lacustrine rocks, Picard and High (1972) list and evaluate bedding characteristics, facies geometry, biofacies, and other factors by which lake sediments can be distinguished from marine and other nonmarine sediments. Some of these features observed in the northern Cady Mountains sequence of the Hector Formation include: (a) evenly laminated, varve-like sedimentary structures in some mudrock units (fig. 14A), indicating quiet-water suspension deposition on a seasonal or rhythmic basis; (b) the texturally massive and structureless fabric of many mudrock units, suggesting either the absence of tractive currents or the homogenizing effect of bioturbation; (c) the occurrence of gypsum seams and limestone beds, both indicating deposition in standing bodies and pools of water rather than deposition from flowing water; (d) the lateral persistence of some mudrock intervals and associated limestone beds, indicating the sheet-like rather than lenticular geometry of the deposits; and (e) the presence of root casts in some mudrock, siltstone, and limestone units, indicating the localized growth of marsh vegetation as ephemeral ponds and pools became choked with fine aggrading sediment.

The limestone beds themselves require an origin in semi-permanent standing bodies of water. The carbonate consists of fine lime mud (micrite) that was generated by carbonate-secreting aquatic algae, or perhaps was precipitated inorganically in warm lake shallows. Moreover, the limestone beds contain ostracodes whose modern analogues are found in fresh water lakes.

Age and Correlation

An age for the Hector Formation in the northern Cady Mountains can be interpreted with confidence based on mammalian fossils and based on radiometric age determinations (fig. 21, column VIII). Fossil mammals indicate that the Hector Formation is at least early Miocene (early to late Hemingfordian in terms of the North American Land Mammal Ages). Provincial epoch assignments follow those of Wood, and others (1941). Fossils were collected from several horizons within the Hector Formation (figs. 4, 21). The lowest collections occur 80 ft (24 m) below the base of the basalt unit (Tmhb), and the highest collections occur approximately 725 ft (22 m) above the top of the basalt. Potassium/argon age determinations were made at three levels within the Hector Formation (fig. 4). An age of 22.9 $\pm$ 0.4 m.y.b.p. was determined for an air-fall tuff bed at the base of measured section CADY-I. An average age of 18.6 $\pm$ 0.2 m.y.b.p. was determined for the basalt unit near the middle of the Hector sequence. An age of 17.9 $\pm$ 0.3 m.y.b.p. was determined for the rhyolitic ash-flow tuff which occurs in the upper third of the Hector sequence. The

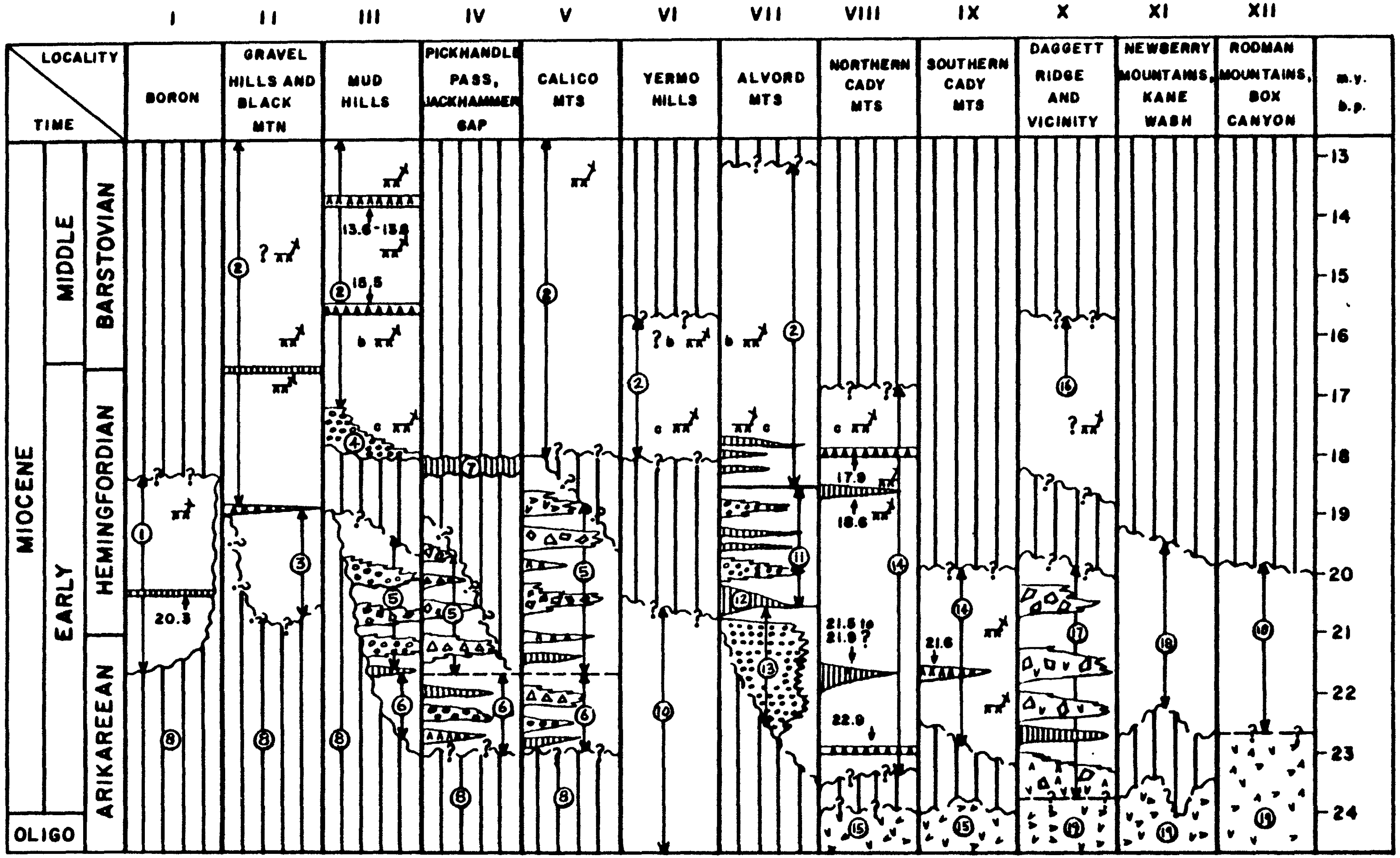

Figure 21.--Correlation of various Miocene sequences that occur in the central Mojave Desert. Correlations discussed in the text. (1) Tropico Group; (2) Barstow Formation, unnamed member of Dibblee (1968); (3) beds assigned to Pickhandle Formation and Opal Mountain Volcanics by Dibblee (1968); (4) Barstow Formation, Owl Conglomerate Member of Dibblee (1968); (5) Pickhandle Formation of McCulloh (1952) and Dibblee (1968); (6) Jackhammer Formation of McCulloh (1952) and Dibblee (1968); (7) "Lane Mountain Volcanics" of McCulloh (1952); (8) pre-Cenozoic crystalline rocks underlying Cenozoic section; (9) unnamed beds, Yermo Hills; (10) unexposed beds inferred to underlie (9); (11) Spanish Canyon Formation of Byers (1960); (12) Alvord Peak Basalt of Byers (1960); (13) Clews Fanglomerate of Byers (1960); (14) Hector Formation of Woodburne and others (1974) in the Cady Mountains area (Tb, Tbb, Tfb, Ta, Tab, Tt, Tfa, Tg, Tss, Tl of Dibblee and Bassett, 1966); (15) unnamed volcanogenic rocks which underlie the Hector Formation in the Cady Mountains area; (16) unnamed sedimentary rocks of Miocene age (Tss, Tsc, Tst, Tsl, Tsg of Dibblee, 1970); (17) unnamed sedimentary and volcanic rocks of (?) Miocene age (Tfp, Tpb, Tgb, Tbu, Tag of Dibblee, 1970); (18) unnamed sedimentary rocks of Miocene age (Tsf, Tsb, Tsc, Tss, Tsg, and Tst of Dibblee, 1964); (19) unnamed volcanic and sedimentary rocks of (?) Miocene age (Tif, Tap, Tb, Tf, Tt, Ts, and Ta of Dibblee 1964b). K/Ar dates in this figure are from: Armstrong and Higgins, 1973; Evernden and others, 1964; Woodburne and others, 1974; Moseley, 1978; Lindsay, 1972, and this report. Where necessary, K/Ar ages have been recalculated according to Dalrymple(1979, table 2, p. 559). b = occurrence of <u>Brachycrus buwaldi</u>; c = occurrence of <u>Merychippus carrizoensis</u>.

oldest of these radiometric ages derives from a level several hundred feet below early Hemingfordian fossil mammals, and indicates that in the northern Cady Mountains the Hector Formation includes early Miocene rocks equivalent to the Arikareean Land Mammal Age (as calibrated by Evernden and others, 1964).

The Hector Formation in the northern Cady Mountains is partially time-correlative with a number of Miocene sedimentary/volcanic sequences that occur in the central Mojave Desert region. One possible model for the correlation of these various rock units is summarized in figure 21. Some of these correlations have been suggested by earlier workers: typically these represent confident correlations that are based on vertebrate fossil collections, or that are based on radiometric age determinations. Other correlations are speculative in nature because they suffer from indadequate temporal control, and these are subject to revision as more age data become available.

Although few stratal sequences in the central Mojave Desert provide the temporal control necessary for detailed time-stratigraphic correlation, a general time-space model for the various Miocene rock successions nevertheless can be approximated. This approximation is based partly on limited faunal control, and partly on consistent patterns in vertical stratigraphic succession that occur from locality to locality. For example, in many local sequences a younger group of prevailingly alluvial Miocene rocks (late Arikareean or Hemingfordian or Barstovian in age) is separated by an unconformity from an older group of prevailingly volcanogenic lower Miocene to (?) upper Oligocene rocks (fig. 21). Although each local unconformity may or may not be of the same duration and magnitude, and although the local unconformities may not be correlative with each other, it is apparent that a younger group of sedimentary/volcanic events is separated from an older group of sedimentary/volcanic events throughout the central Mojave Desert. Within this general framework the problem becomes one of correlating regionally within each group, and determining the degree to which the two groups are entirely superpositional or partly coeval on a regional basis. This section is devoted to correlation within the group of prevailingly sedimentary sequences.

The northern Cady Mountains sequence of the Hector Formation is partly correlative with the type Hector Formation in the southern Cady Mountains (fig. 21, column IX; Woodburne and others, 1974). In its type area, the Hector Formation ranges in age from late early to early middle Miocene (late Arikareean to early Hemingfordian). This age determination is based on mammalian fossils that were collected from within 50 ft (15 m) of the base of the formation to within 300 ft (91 m) of its top (Woodburne and others, 1974, p. 15). This age is supported by a radiometric date of 21.6 m.y.b.p. obtained from a tuff near the middle of the sequence. Thus, the Hector Formation in its type area overlaps in age with the lower and middle portions of the northern Cady Mountains sequence of the Hector Formation (fig. 21, columns VIII and IX). The type Hector unconformably overlies andesitic agglomerate and other volcanogenic units (Woodburne and others, 1974) herein assigned to the prevailingly volcanogenic suite. The type Hector thus occupies the same relative stratigraphic position with respect to a pre-Hector unconformity and with respect to an older volcanogenic terrain as does the Hector Formation in the study area (fig. 21, columns VIII and IX).

The Hector Formation in the northern Cady Mountains is time-correlative with unnamed Miocene sedimentary rocks in the Daggett Ridge area (fig. 21, column X), although this correlation cannot be made with much precision. The rocks at Daggett Ridge have been mapped by Dibblee (1970, Tss, Tsc, Tst, Tsl, Tsg), who reports Hemingfordian vertebrate fossils from an undisclosed part of the sequence (R.H. Tedford in Dibblee, 1970, p. 1). A generalized Hemingfordian age for some of the rocks at Daggett Ridge thus indicates their correlation with some part of the Hemingfordian sequence in the study area. However, this correlation must remain speculative until the existing Daggett Ridge vertebrate fauna is studied in more detail, and until a complete age-range for the unnamed Miocene sedimentary succession is determined. It is worth noting that, although age relationships in the Daggett Ridge sequence are poorly known, these rocks exhibit the same relative vertical stratigraphy as do many other mid-Tertiary sedimentary/volcanic sequences in the central Mojave Desert (fig. 21, column X): a younger group of Miocene alluvial/lacustrine sedimentary rocks and associated volcanic rocks is separated by an unconformity from older sedimentary and volcanic rocks. Dibblee (1970) indicates that the latter (Tfp, Tpb, Tgb, Tbu, Tag) constitute the youngest part of a thick sequence of sedimentary and volcanic rocks that crop out in the Newberry Mountains (fig. 21).

The Hector Formation in the northern Cady Mountains is partially time-correlative with the Barstow formation in the Mud Hills, Calico Mountains, Alvord Mountains, Yermo Hills, and Gravel Hills (fig. 21). In the Mud Hills, the Barstow Formation contains vertebrate fossils of late Hemingfordian and Barstovian age (fig. 21, column III; Lewis, 1968). Lewis (1968, p. C75) recognizes three fossiliferous intervals in the Barstow Formation of the Mud Hills: (1) an older faunal assemblage that contains the horse, Merychippus carrizoensis (= tehachapiensis); (2) a middle faunal assemblage that begins approximately 650 ft (198 m) stratigraphically above the oldest assemblage, and that contains the diagnostic oreodont Brachycrus buwaldi; and (3) a younger fossil assemblage of diverse taxa which typifies the Barstovian Land Mammal Age. Lewis concluded that the oldest fossil assemblage is late Hemingfordian in age, while the younger two assemblages are Barstovian in age. The oldest faunal assemblage is characterized by the horse, Merychippus carrizoensis (= tehachapiensis). This taxon occurs in the Upper Cady Mountains local fauna in the northern Cady Mountains. Provided that the biochron of M. carrizoensis is restricted to the Hemingfordian, the lower part of the Barstow Formation in the Mud Hills overlaps in age with the Hector Formation of the northern Cady Mountains (fig. 21, columns III and VIII).

In the Pickhandle Pass area of the western Calico Mountains (fig. 21, column IV), the Barstow Formation unconformably overlies unfossiliferous strata of the Pickhandle and Jackhammer Formations (Dibblee, 1968; McCulloh, 1952). These rock units herein are included within the prevailingly volcanogenic suite because they are dominated by volcanic flows and tuffs. These two formations thus would seem to be analogous with older volcanic and sedimentary rocks in the northern Cady Mountains that unconformably underlie the Hector Formation, and with other prevailingly volcanogenic rocks that occur regionally beneath primarily alluvial Miocene sedimentary rocks (plate 6). However, preliminary radiometric age determinations by Dennis Burke and his colleagues with the U.S. Geological Survey, Menlo Park, and by the author and Janet Morton of the U.S.G.S., suggest that the Pickhandle Formation may in part by young enough to overlap in age with some part of the lower Hector Formation in the northern Cady Mountains. If confirmed, this correlation would indicate that the prevailingly alluvial suite and the prevailingly volcanogenic suite overlap in age on a regional basis.

The Barstow Formation in the eastern Calico Mountains is sparsely fossiliferous. A fragmentary specimen of Merychippus intermontanus was collected from the upper part of the section (McCulloh, 1952; Tedford, in Dibblee, 1970, p. 1), thus indicating a Barstovian age for that portion of the sequence (fig. 21, column V). Lewis (in Dibblee, 1968, p. 34) states that middle Miocene (Hemingfordian) fossils were collected from the Barstow Formation in the Calico Mountains, but he did not detail which taxa were represented or from what part of the section the fossils were recovered. Thus, temporal correlations inferred to exist between the northern Cady Mountains sequence of the Hector Formation and those parts of the Calico Mountains sequence of the Barstow Formation that occur below M. intermontanus must remain speculative until age data from the Calico Mountains are more fully documented. As in the Mud Hills, the Barstow Formation in the Calico Mountains unconformably overlies the Pickhandle and Jackhammer Formations (Dibblee, 1970), herein interpreted as part of the prevailingly volcanogenic suite.

The Barstow Formation in the Yermo Hills contains vertebrate fossils of late Hemingfordian and Barstovian age (unpublished collections in the Department of Earth Sciences, UCR, and Dibblee and Bassett, 1966a). Hence, these rocks overlap in age with the upper portion of the Hector Formation in the northern Cady Mountains (fig. 21, column VI). In the nearby Harvard Hills, rocks possibly equivalent to the Barstow Formation (Tl, Ts, and Tsf of Dibblee and Bassett, 1966a) unconformably overlie a sequence of fanglomerate and andesitic breccia (Tf and Tab of Dibblee and Bassett, 1966a). The latter units possibly are analogous to the prevailingly volcanogenic suite in the northern Cady Mountains. Although pre-Barstow units are not exposed in the Yermo Hills, it is likely that an older sedimentary/volcanic sequence underlies the Barstow Formation here as it does in the Calico Mountains and in the Harvard Hills. This interpretation is incorporated in figure 21, column VI.

Time-stratigrahpic relations between the Hector Formation in the northern Cady Mountains and sedimentary/volcanic rocks in the Alvord Mountains are not completely understood. As shown in figure 21, columns VII and VIII, a relatively precise correlation exists between upper Hemingfordian rocks in the study area that contain Merychippus carrizoensis (= tehachapiensis), and rocks bearing M. carrizoensis (= tehachapiensis) in the Alvord Mountains that Byers (1960) assigned to the Barstow Formation. Below the level of M. carrizoensis (= tehachapiensis) however, correlation between the northern Cady Mountains and the Alvord Mountains is more speculative. No radiometric or paleontologic ages have been determined for the lower part of Byers' Barstow Formation or for the underlying Spanish Canyon Formation, Alvord Peak Basalt, and Clews Fanglomerate, and hence their correlation with rocks in the study area must remain speculative. The writer believes that the entire succession in the Alvord Mountains is part of the suite of prevailingly alluvial/lacustrine rocks in the central Mojave Desert. By this model, the voluminous basalt flows of the Alvord Peak Basalt are interpreted as locally thick manifestations of volcanic events which produced the basalt unit (Tmhb) in the study area. By the same reasoning, tuffaceous intervals in the Spanish Canyon Formation probably correspond with air-fall tuff beds that occur in the northern Cady Mountains sequence of the Hector Formation. In short, the writer does not believe that the Alvord Mountains succession is part of the prevailingly volcanogenic suite, although the Clews Fanglomerate may overlap in age with the Pickhandle Formation in the Mud Hills and Calico Mountains (fig. 21).

In the Black Canyon/Gravel Hills area, three localities within the Barstow Formation have yielded fossils of Barstovian age (Lewis in Dibblee, 1968). Lewis (p. 35) states that one other locality (Red--No. D306) produced fossils that "may be somewhat older," but he does not list either the taxa or the stratigraphic horizon from which they came. This questionably older faunal assemblage may be partially time-correlative with the Upper Cady Mountains local fauna (fig. 21, columns II and VIII). Until temporal and stratigraphic control have been improved for the Gravel Hills/Black Canyon sequence, however, the generalized temporal relationships suggested in figure 21 must remain speculative.

In the Black Canyon/Gravel Hills area, the Barstow Formation overlies the Pickhandle Formation, although only an arbitrary contact can be placed between the two formations in the Black Canyon area (Dibblee, 1968, p. 30). The Pickhandle Formation is intercalated with a series of siliceous tuffs and flows that have been mapped separately by Dibblee (1968) as the Opal Mountain Volcanics. Age relations of the pre-Barstow units are uncertain, and precise correlation of these units must await ongoing radiometric age determinations by Dennis Burke and his colleagues with the U.S. Geological Survey. Preliminary radiometric dates suggest that the Pickhandle/Opal Mountain Volcanic sequence may overlap in age with parts of the Hector Formation in the Cady Mountains (fig. 21).

The Hector Formation in the northern Cady Mountains is partially or totally time-correlative with the Tropico Group as exposed in the vicinity of the town of Boron in the western Mojave Desert (fig. 21, column I). The Boron fauna was collected from the unnamed upper part of the Tropico Group in the U.S. Borax and Chemical Company's open pit mine. The Boron fauna occurs 480 ft (146 m) above the Saddleback Basalt (Whistler, 1965; Dibblee, 1967), from which a potassium/argon date of 20.3 $\pm$ 0.7 m.y.b.p. was obtained by Armstrong and Higgins (1973). Whistler (1965) considered the Boron fauna to be no younger than early to middle Hemingfordian or approximately early Hemingfordian in age. The author believes it to be approximately the same age as or slightly older than the Lower Cady Mountains local fauna which occurs just above and below the basalt unit dated at 18.6 $\pm$ 0.2 m.y. The Boron fauna is definitely older than the Upper Cady Mountains local fauna.

The Tropico Group in the Kramer Borate district (e.g. Boron, fig. 21, column I) consists of tuffaceous and carbonate rocks, chert, shale, sandstone, congolmerate, breccia, and basalt. In the Kramer borate district, the Tropico Group unconformably overlies pre-Tertiary basement (Dibblee, 1967, fig. 46). A similar setting for the Tropico Group occurs in the nearby Kramer Hills.

In the Kane Wash area of the Rodman Mountains Quadrangle a 10,000 ft (3,048 m) sequence of unnamed volcanic and sedimentary rocks is overlain unconformably by a 3000 ft (914 m) sequence of unnamed, sedimentary rocks and subordinate volcanic flows (fig. 21, column XI). Rocks beneath the unconformity (Tb, Tt, Tf, Ts, and Ta of Dibblee, 1964b) may represent the prevailingly volcanogenic suite whereas rocks above the unconformity may represent the prevailingly alluvial/lacustrine suite. The latter (Tsf, Tsb, Tsc, Tss, Tsg, and Tst of Dibblee, 1964b) are believed to be time-correlative with some portion of the Hector Formation in the northern Cady Mountains.

Dibblee (1964b) maps the same or very similar stratigraphic relationships in the Box Canyon area of the Rodman Mountains as he does in the Kane Wash area, except that no unconformity separates the sedimentary/volcanic suite from the underlying prevailingly volcanogenic suite. As in the Kane Wash area, rocks in the sedimentary/volcanic suite in the Box Canyon area (Tsf, Tsb, Tsc, Tss, Tsg, and Tst of Dibblee, 1964b) are believed to be time-correlative with some portion of the Hector Formation in the northern Cady Mountains.

Although this correlation is speculative, it is suggested by the fact that the younger sedimentary rocks in the Rodman Mountains quadrangle occupy the same relative stratigraphic position with respect to the underlying older volcanogenic rocks as does the Hector Formation in the study area and in the southern Cady Mountains (fig.21, columns VIII, IX, XI and XII). In their discussion of the Hector Formation in the southern Cady Mountains, Woodburne and others (1974, p. 14-15) also indicate a correlation between the Hector and unnamed sedimentary rocks in the Box Canyon area of the Rodman Mountains.

In summary, mammalian fossils and radiometric age determinations have shown that the northern Cady Mountains sequence of the Hector Formation is early Miocene (Arikareean to at least late Hemingfordian) in age. The Hector Formation in the northern Cady Mountains is partially time-correlative with the type Hector Formation of the southern Cady Mountains, which ranges from late Arikareean to early Hemingfordian in age. In addition, the northern Cady Mountains sequence of the Hector Formation overlaps in age with several other fossiliferous sequences in the central Mojave Desert region, and may also overlap in age with several unfossiliferous sequences in the vicinity (fig. 21). The fossiliferous sequences include: (1) the Barstow Formation in the Mud Hills, Yermo Hills, Alvord Mountains, Calico Mountains, and Gravel Hills/Black Canyon area; (2) the unnamed Daggett Ridge sequence; and (3) the Tropico Group as exposed in the Kramer Borate District. The unfossiliferous sequences believed to be partially or entirely time-correlative with the Hector Formation include (4) the Spanish Canyon Formation, Alvord Peak Basalt, and Clews Fanglomerate in the Alvord Mountains; (5) parts of the Pickhandle Formation in the Pickhandle Pass area; and (6) rocks of the prevailingly alluvial/lacustrine suite represented in the Kane Wash and Box Canyon areas of the Rodman Mountains. Further research will be required to establish the temporal control necessary to determine if these presently unfossiliferous rock units are indeed correlative with the northern Cady Mountains sequence of the Hector Formation.

Paleogeographic Relationship between the Northern Cady Mountains and other Miocene Sequences in the Central Mojave Desert Region

One of the questions that this study seeks to answer concerns the paleogeographic relationship between Miocene sedimentary and volcanic rocks in the northern Cady Mountains and other Miocene sedimentary and volcanic sequences scattered throughout the central Mojave Desert (fig. 3, plate 7). One of two distinct paleogeographic models seems to be applicable in the central Mojave Desert region during Miocene time: (1) the paleogeographic setting consisted of a network of geographically isolated intermontane basins, or (2) the paleogeographic setting consisted of a single large sedimentary basin or trough within which there was depositional and stratigraphic continuity.

In the former case, sedimentary and volcanic events in each local intermontane basin would have been independent of sedimentary and volcanic events in other intermontane basins: general similarities in stratigraphic sequence from basin-to-basin would be fortuitous, and would reflect the fact that the region as a whole was undergoing sequential stages of local-basin inception, followed by sediment-filling accompanied by contemporaneous volcanism. In the case of a single region-wide basin, sedimentary and volcanic events in each local area still would be more-or-less independent of similar events in other areas, but local depocenters and their basin-fillings would interfinger laterally. Because of this lateral continuity, general similarities in stratigraphic sequence from area-to-area would be expected. However, local differences in lithology and stratigraphy would also be predictable considering the inherent variability of alluvial and lacustrine sedimentation patterns and considering the patchy geographic distribution of active volcanic centers.

There is no way to verify either paleogeographic model because of the existing geographic isolation of the Miocene sedimentary/volcanic sequences in the central Mojave Desert (fig. 3). Application of either model becomes a matter of interpretation. In the writer's view the close coincidence of the various Miocene sequences within a relatively limited geographic area together with their overall lithologic similarity. Support the interpretation that these sequences are genetically related and geographically coextensive. Original stratigraphic continuity between these various sequences is also supported by consistent patterns in vertical stratigraphic succession that occur from locality-to-locality. (See section on Age and Correlation and figure 21.) Accordingly, a paleogeographic model incorporating a single region-wide depositional basin is adopted in this paper. The sedimentary/volcanic sequence of the Hector Formation in the northern Cady Mountains is interpreted as having accumulated within this basin, herein called the Barstow basin following Dibblee (1967d). Miocene sequences in the southern Cady Mountains, Rodman Mountains, Newberry Mountains, Daggett Ridge area, Yermo Hills, Calico Mountains, Alvord Mountains, Mud Hills, and Gravel Hills also accumulated within the Barstow basin. Collectively, these sequences range from late Arikareean through Barstovian in age, and together they constitute a regionally extensive episode of prevailingly alluvial and lacustrine sedimentation.

Precedence for such a paleogeographic model has in part been established by earlier workers (Bowen, 1954; Byers, 1960; Dibblee, 1967d, fig. 71). The Barstow basin of Bowen (1954, p. 81, 117) was a northwest-trending trough receiving sediments from both north and south. Bowen's Barstow trough, however, was primarily restricted to the Barstow Syncline area of the Mud Hills and to portions of the adjacent Calico Mountains and Gravel Hills. Byers (1960 p. 34) suggested that the depositional basin for his region-wide Barstow Formation included the Gravel Hills/Black Canyon area, the Mud Hills, the Calico Mountains, and the Alvord Mountains. Dibblee (1967d, fig. 71) implied that the Barstow basin extended from the Gravel and Mud Hills east beyond the town of Barstow, although he did not directly state that more-easterly Miocene sequences formed within this basin. Bassett and Kupfer (1964) also envisioned a region-wide depositional province within which late-Cenozoic sedimentary and volcanic rocks are assumed to have accumulated.

It should be recognized that each local Miocene sequence represents a somewhat different portion of the late Arikareean through Barstovian age span embodied by the regionally-extensive sequence as a whole (fig. 21). This situation is predictable based on the assumption that local depocenters within the main depositional basin are permitted to develop at their own rate and to evolve in response to local tectonic controls and local volcanic events. Local tectonism in particular is likely to be the most important control on local base levels: it would be the guiding factor in determining whether or not sediments would be deposited at a given site within the regional basin, and in determining ultimately what kind of depositional style would occur at a given site. Both secular and geographic variation in subsidence rates and sedimentation rates would be expected to have occurred during the evolution of the regional basin. By this logic, the time/space distribution of active deponters within the regional basin was probably patchy at any given moment, and this distribution pattern would be likely to shift with time under the guidance of shifting tectonism and adjusting base levels. Alluvial and lacustrine environments would be expected to migrate geographically, thus yielding time-transgressive patterns of rock-unit distribution (fig. 21). In short, each local Miocene succession could easily represent a somewhat different portion of the total age span embodied by the regionally extensive sequence as a whole. Thus, discrepancies in age and lithology that occur between various Miocene sequences are herein interpreted to reflect tectonically controlled alluvial and lacustrine sedimentation that occurred within a single regional basin, rather than independently operating depositional events that occurred within several isolated intermontane basins.

The paleogeographic configuration of the regionally extensive Barstow basin can be reconstructed in only a general way. The limited number of Miocene sedimentary/volcanic sequences so far studied and the geographic separation between these sequences prevent the delineation of exact boundaries for this basin and discourage the recognition of regional facies patterns within the basin itself. As envisioned in this report, the regional Barstow basin was essentially an irregularly elongate, east-trending trough (easttrending with respect to the earth's present magnetic field). The elongate basin was probably no wider than a few tens of miles, and extended a minimum of 75 mi (120 km) westward from at least the Cady Mountains to at least the Gravel Hills (plate

6). The eastern and western limits of this trough are not established. It is likely that it extended a few miles eastward beyond the Cady Mountains, where it most likely included unnamed and undated sedimentary rocks that cap Pacific Mesa (Ts and Tc of Dibblee, 1967a) and that occur on the east flanks of the Cady Mountains (Tvf of Dibblee, 1967b; plate 6). The basin may well have continued westward from the Mud Hills to include depocenters at Boron and the Kramer Hills, where lower and middle Miocene sediments and volcanic flows and tuffs accumulated (plate 6). Thus, in its broadest sense, the Barstow basin was an irregularly elongate depositional province that may have extended for as much as 100 mi (167 km) in a nearly east-west direction but that was probably no more than 20 to 30 mi (32 to 48 km) wide along its north-south axis (plate 6).

The original geographic orientation of this basin may have been altered to some degree by post-Miocene structural rotation of the Mojave block and disruption of the basin by right-lateral strike-slip faulting. The idea of strike-slip motion on some of the major northwest-trending faults in the western Mojave Desert was first proposed by Dibblee (1961). More recently, Garfunkel (1974) proposed that northwest-trending faults throughout the Mojave Desert region underwent major right-lateral strike-slip movement during late Cenozoic time. Garfunkel's (1974, fig. 3) model postulates maximum slips ranging from 10 to 40 km (10 to 20 km minimum) for the Pisgah, Calico, Camp Rock, Lenwood and Helendale faults (plate 6, this report). Geologic features utilized by Garfunkle in proposing these displacements include: (1) assumed offsets of Tertiary volcanic and sedimentary rocks; (2) assumed offsets of the southern boundary of Mesozoic metavolcanic rocks; (3) assumed offsets of Paleozoic marine sedimentary rocks; and (4) assumed offsets of metasedimentary rocks. Because potential large-scale disruption of Miocene rock units by strike-slip faulting has bearing on paleogeographic relations between rocks in the northern Cady Mountains and other Miocene sedimentary/volcanic sequences, Garfunkel's (1974) model for strike-slip displacements in the central Mojave Desert will be critiqued briefly.

Although relatively detailed 15 minute geologic quadrangle maps were available (e.g., Dibblee, 1964a,b, 1966, 1967a,b,c, 1968, 1970; Dibblee and Bassett, 1966a,b), Garfunkel (1974) used for his geologic base the two degree geologic sheets published by the California Division of Mines and Geology (1:250,000 scale; Jennings and others, 1962; Rogers, 1967). A perusal of the more detailed quadrangle maps indicates that Garfunkel may have been correct in his assessment of displacements along faults in the western-most Mojave Desert, but his proposals for large displacements along fault systems in the east-central Mojave Desert seem to be excessive based on interpretations discussed below.

In the westernmost Mojave Desert, Garfunkel (1974) suggested a separation of 10 to 15 km of right-lateral offset on the Helendale Fault. Although this displacement cannot be documented by matching specific rock units across the fault, nonetheless, the southeastern boundary of the Triassic metavolcanic complex (Sidewinder volcanic complex and related units; Dibblee, Apple Valley quadrangle, 1960; Rogers, 1967; B_3 and B_4 of Garfunkel, 1974, fig. 3) may have been offset by as much as 10 to 15 km (plates 6 and 7). The proximity of the Helendale Fault to the San Andreas Fault may account for this presumed degree of right-lateral offset on the Helendale Fault zone.

Garfunkel's estimates for displacements on the Lenwood, Camp Rock, Calico, and Pisgah-Bullion fault zones can be challenged on the basis of mapping by T.W. Dibblee. The latter was able to establish specific, narrowly defined rock units which provide a more firm basis for recognizing potentially offset terrains. Small-scale compilations represented by the two degree state sheets tend to obscure this detail by grouping related rocks into generalized categories. For example, rocks shown on the San Bernardino sheet as a uniform sequence of Jurassic and Triassic metavolcanic rocks at some localities consist of a suite of distinctive rock units: in the Rodman Mountains and Ord Mountains quadrangles, Dibblee (1964a,b) recognized several units within his intrusive porphyry volcanic complex. In addition, he was able to recognize certain distinctive granitoid rocks in these and other quadrangles. When the state sheets are consulted, apparent offsets between generalized map units appear very convincing. In virtually ever case, however, these apparent offsets can be disputed when Dibblee's narrowly defined map units are matched across the Lenwood, Camp Rock, Calico, and Pisgah-Bullion fault systems. Plate 6 of this report summarizes the existing distributions of some of these key rock units. Plate 7 is a palinspastic reconstruction for rocks in the central Mojave Desert that results when presumably offset rock units shown on plate VI are restored to their orignally juxtaposed configurations.

The following right-lateral separations are suggested in this report: (1) approximately 1 to 1.5 km on the Lenwood Fault, based on offset of a stratigraphic contact in the Daggett Ridge area (plate 6, DR; geologic base from Dibblee, 1970); (2) approximately 3.75 km on the Camp Rock fault zone, based on a variety of offset basement contacts (plate 6, middle of Rodman Mountains quadrangle, Dibblee, 1964b); (3) a maximum of 8 km on the Calico fault zone, based on a variety of offset basement contacts, offset mid-Tertiary sedimentary and volcanic rocks, and offset structures (plate 6, northeast corner of Rodman Mountains quadrangle, Dibblee, 1964b), and (4) an offset of <1 km on the Pisgah-Bullion fault zone based on offset of a Quaternary lava flow (plate 6, north-central portion of Lavic quadrangle, Dibblee, 1966). No other offset of older rocks on the Pisgah-Bullion fault zone is indicated by Dibblee's mapping (1966, 1967c). Presumed offset of a contact between Mesozoic granitoid rocks and onlapping mid-Tertiary sedimentary and volcanic rocks used by Garfunkel (1974, fig. 3, A_1, A_2, A_3, A_4) to suggest large-scale strike-slip separations on these fault systems is not accepted in the present report. In the Newberry and Rodman Mountains this contact is a remarkable buttress unconformity (Dibblee, 1971): in the Bullion Mountains, the supposed offset equivalent of this buttress unconformity is depicted in Dibblee's (1966, 1967c) cross-sections as a normal nonconformity, not as a buttress unconformity as it would have to be if this contact here were the offset equivalent of that in Newberry-Rodman district.

As envisioned in the present report, the paleogeographic distribution of local depocenters within the region-wide Barstow basin probably has not been very much disrupted by post-Miocene strike-slip displacement along existing fault zones. When the minimal separations suggested above are accommodated, an inferred palinspastic reconstruction of the Barstow basin (plate 7) differs only slightly from the proposed paleogeographic configuration of this basin based on existing outcrops of Miocene sequences interpreted to have formed within this region-wide depositional province (plate 6).

The model of a limited right-lateral separation on the Lenwood, Camp Rock, Calico, and Pisgah-Bullion fault zones is supported, at least in part, by offsets of isochron contours for basement rocks in the central and western Mojave Desert region (F.K. Miller, personal communication, 1978).

It is likely that the overall elongate geometry of the Barstow basin was complicated by a variety of embayments and other geomorphic irregularities. These paleogeographic elements probably included higher standing peninsular promontories or highland re-entrants that projected into the main basin, as well as higher standing insular monadnocks of basement rocks or older sedimentary and volcanic rocks that may have projected above the regional alluvial/lacustrine surface. For example, Dibblee (1967d, fig. 76; 1968, p. 31-33) has reconstructed a highland re-entrant that extended into the Barstow basin south of the Gravel and Mud Hills. An analogous paleogeographic element seems to have existed as a higher standing terrain that separated the Miocene depocenter in the northern Cady Mountains from depocenters in the southern Cady Mountains that were receiving sediments assigned to the Hector Formation of Woodburne, Tedford, Stevens, and Taylor (1974). Sedimentary rocks in the type Hector Formation crop out only 8 to 10 mi (14 to 17 km) southwest of rocks in the study area. Woodburne and co-workers indicate a northern and northeastern source for sediments in the Hector formation (1974, p. 14-15), and evidence has been summarized in the present report that suggest a southern, southwestern, and southeastern source for sedimentary rocks exposed in the northern Cady Mountains. It is likely that this source area served as a common provenance for sediments in both the northern and southern Cady Mountains, and that it formed a high-standing terrain that locally separated the two depocenters. This paleogeographic element is envisioned as a peninsular re-entrant into the Barstow basin, although alternatively it may have been a monadnock-like paleogeographic feature. Sediments accumulating in the northern Cady Mountains may ultimately have interfingered with those accumulating in the southern Cady Mountains around the western end of the inferred promontory and/or across low saddles and passes that may have provided local connections between the two depocenters.

The precise distribution of local depocenters and the time/space evolution of depositional facies patterns throughout the region-wide basin are not yet known in detail. As indicated by the correlations suggested in figure 21, it is likely that Hector-type alluvial sedimentation began at somewhat different times in different local areas within the regional trough. This would account, for example, for the inception of alluvial/lacustrine sedimentation in the Cady Mountains area during late early Miocene (late Arikareean) time, and for the later inception of this style of sedimentation in the type area of the Barstow Formation during late middle Miocene (middle to late Hemingfordian) time. As discussed above, these time-transgressive patterns of sedimentation are attributed to local tectonic control of local base levels. Ultimately, by about late middle Miocene (late Hemingfordian) time, alluvial/lacustrine sedimentation was probably occurring simultaneously throughout the Barstow basin, thus providing geographic and stratigraphic continuity between the local depocenters. This regional stratigraphic continuity is inferred to have persisted despite the presence of peninsular highland re-entrants and insular monadnocks that probably complicated the basinal configuration.

In its broadest sense, the Barstow basin is interpreted to be a major structural and sedimentary trough that developed in the central Mojave Desert during the late Tertiary. This inferred trough is believed to have evolved in early Miocene time (about 23 m.y.b.p.), and during the remainder of the Miocene it became an elongate center for volcaniclastic alluvial/lacustrine sedimentation. Materials that accumulated in this inferred trough are now exposed in geographically isolated sequences that originally had contiguous depositional relations and lateral stratigraphic continuity. Lower Miocene (upper Arikareean through upper Hemingfordian) sedimentary and volcanic rocks in the northern Cady Mountains represent one of these sequences that accumulated near the known eastern end of the Barstow trough. Although it is only a concept now, when its geographic distribution and sedimentary history are fully documented and when the chronology of its volcanic history is better understood, the Barstow trough may provide key insight into the paleogeographic and plate tectonic evolution of the Mojave Desert province.

Younger Alluvial Units

Within the study area, four late Cenozoic alluvial units have been mapped. They are, in ascending order: (1) the late Tertiary and Quaternary fanglomerate and gravel unit; (2) the Quaternary older gravel unit; (3) the Quaternary older alluvium unit; and (4) the Quaternary younger alluvium unit. These four units will be discussed only briefly as they are not the main focus of this report.

Fanglomerate and Gravel

Gently dipping, very coarse sedimentary rocks of Quaternary/Tertiary age cap ridges in the southern and southeastern portion of the study area. No formal lithostratigraphic name has been applied to these rocks. Dibblee and Bassett (1966b) included these rocks in their units Taf, Tvf and Tgf.

More than 400 ft (122 m, estimated from map) of yellowish brown pebble-cobble-boulder conglomerate, conglomeratic sandstone, fanglomerate and gravel are included in the fanglomerate and gravel unit within the study area. This value is a minimum thickness, however, for the upper boundary of the unit is not exposed in the mapped area. An angular unconformity separates this coarse sedimentary sequence from the underlying Hector Formation. The unit is unconformably overlain by the older gravel unit and by the older alluvium unit.

The clastic constituents of the fanglomerate and gravel unit are about equally divided between (1) intermediate and mafic volcanic rocks, and (2) granitoid rocks. The clasts are primarily angular to subangular and range in size from granule to boulder. The matrix ranges from silt- to sand-size particles. The strata display both large- and small-scale cross-lamination and channel structures. The coarseness of the sediments and the structure indicate a fluvial origin for the unit.

Older Gravel

A dissected unit of older gravel consisting of weakly consolidated pebble-cobble gravel caps ridges in the northern portion of the study area (figs. 18, 22). Strata of the older gravel sequence are crudely bedded. The beds are either flat-lying or dip to the east at very shallow angles. The maximum exposed thickness of the unit is approximately 40 ft (12 m, estimated from map). An angular unconformity separates the older gravel unit from the Hector Formation, from the older fanglomerate and gravel unit, and from the older alluvium unit. The age of the older gravel unit is presumed to be Pleistocene.

The older gravel is brown in color. Clasts within the older gravel consist predominantly of subangular to well rounded fragments of Tertiary volcanic rocks derived from the surrounding hills. Well-rounded volcanic and granitic clasts probably represent reworked material from the fanglomerate and gravel unit and from the conglomeratic beds of the Hector Formation. Fragments of the rhyolite ashflow tuff and the basalt of the Hector Formation are present along with detritus from volcanic terrains presently exposed to the south and west of the study area (see Dibblee and Bassett, 1966b).

Older Alluvium

A dissected unit of older alluvium consisting of weakly consolidated sand and pebble-cobble gravel caps low terraces and ridges in the study area (figs. 20, 22). Strata of the older alluvial sequence are crudely bedded. The beds are either flat-lying or dip to the west at very shallow angles. The maximum exposed thickness of the unit is approximately 25 ft (8 m, estimated from map). An angular unconformity separates the older alluvium from the Hector Formation, from the older fanglomerate and gravel unit, and from the older gravel unit. The older alluvium unit is separated from the younger alluvium unit by an angular unconformity. The age of the alluvium is presumably Pleistocene.

Clasts within the older alluvium are composed of subangular to rounded debris derived from the surrounding hills. This debris includes: (1) well-rounded, reworked clasts from the older fanglomerate and gravel unit; (2) detritus from Tertiary volcanic terrains presently exposed to the south and west of the study area (see Dibblee and Bassett, 1966b); and (3) detritus from the conglomerate, rhyolite ashflow tuff and basalt units of the Hector Formation. The clasts are frequently cemented with irregular patches of caliche.

Younger Alluvium

Alluvium consisting of unconsolidated silt, sand and granule-pebble-cobble gravel occurs in stream channels and on adjacent low-lying terraces and overflow channels. For the most part, the sediments are undissected. Individual grains are composed of: (1) angular to rounded material locally derived from the sandstone, siltstone, conglomerate, rhyolite ashflow tuff and basalt of the Hector Formation; and (2) predominantly rounded clasts locally derived from the older alluvial units. An erosional unconformity separates the alluvium from all older units. The age of the younger alluvium is probably very late Pleistocene and Recent.

Figure 22.--Photograph showing relationship of younger alluvial units to older sedimentary units: weakly consolidated, flat-lying sand and pebble-cobble gravel of the older gravel unit (Qog) and of the older alluvium unit (Qoa) unconformably overlie gently dipping strata of the middle member of the Hector Formation (Tmhm).

Structure

No faulting or folding coincident with deposition of the Hector sediments is recognized in the northern Cady Mountains. Following deposition of the sediments, however, the Hector Formation was folded into an open, generally east-trending and east-plunging syncline. The syncline is poorly delineated in the study area due to the fact that (1) the sequence underwent extreme faulting subsequent to folding and (2) much of the Hector sequence is covered by very late Tertiary and Quaternary alluvial units. The faulting disrupted the symmetry of the fold to such an extent that it is not possible to place more than an approximation of the axial plane trace on the map (plate 1). Attitudes on the limbs of the fold range from 4 to 45°. The folding does not affect the younger alluvial units, and thus may be of late Miocene or Pliocene age.

Both major and minor high-angle normal faults disrupt the rocks in the study area (plate 1). With few exceptions, these faults trend in a northerly direction and are downthrown on the western block (although two of the three major faults are down on the east). Throw on the faults ranges from 10 to approximately 300 ft (3 to 91 m), but only three faults have known displacements of 100 ft (31 m) or more. These three faults most strongly affect the fossil-bearing strata, and hence only these three faults will be discussed in detail.

Fault A, which occurs in the southwestern portion of the mapped area (plate 1), is a northeast-trending, northwest-dipping reverse fault. Dip on the fault is approximately 45° to the northwest. Stratigraphic throw on Fault A is estimated to be 300 ft (91 m) or more. This estimate is based on the juxtaposition at the fault plane of the upper contact of the basalt unit with strata which underlie the basalt by approximately 270 ft (82 m).

Fault B is a north-northwest-trending high-angle normal fault which traverses the entire study area. Dips ranging from 58° in the northwest to between 72° and 85° in the south were measured. Stratigraphic throw on Fault B is approximately 50 to 100 ft (23 to 31 m) based on the juxtaposition of sediments below the basalt with sediments above the basalt. The western block of Fault B is downthrown.

Fault C is a sinuous, generally north-trending fault with the downthrown block on the east. The sinuous trend of the structure suggests that both normal and reverse movements have taken place as the fault plane rotated from an easterly dip through 90° to a westerly dip along its trace. Stratigraphic throw on Fault C is difficult to determine due to the different facies opposed across it. In the northern portion of the mapped area, however, the rhyolitic ashflow tuff unit is nearly juxtaposed to the basalt unit, indicating a vertical offset of 260 to 300 ft (79 to 91 m) at that point (assuming a constant sediment thickness). In the southeastern portion of the study area, the rhyolitic ashflow tuff unit is separated from the overlying upper unit of the Hector Formation by Fault C. It was not possible to estimate the amount of offset at this point, and hence the thickness of the upper unit of the Hector Formation was not determined.

At least two episodes of faulting are documented in the northern Cady Mountains. The earliest faulting took place after the folding of the Hector Formation, and prior to deposition of the late Tertiary and Quaternary fanglomerate and gravel unit. Faulting of this age includes Faults A and B, which do not affect the older fanglomerate and gravel unit. The second episode of faulting, represented by Fault C and several faults in the southern portion of the mapped area, took place after deposition of the late Tertiary and Quaternary fanglomerate and gravel unit. This is evident from the fact that the faults cut the late Tertiary and Quaternary fanglomerate and gravel unit as well as the Hector Formation. The second episode of faulting occurred prior to the deposition of the Quaternary older gravel and older alluvium units, because these are not affected by the faulting. Hence, a Quaternary (Pleistocene?) age is suggested for this younger episode of faulting.

Only limited regional significance can be drawn from the structural trends of such a small area. It should be noted, however, that the north-northwest-trending faults of the northern Cady Mountains might reflect stress related to movement on the San Andreas Fault System which lies to the west. In addition, the east and east-northeast-trending faults which occur in the study area may possibly reflect stress related to movement on the Garlock Fault Zone which lies to the north.

BIOSTRATIGRAPHY OF THE HECTOR FORMATION

Mammal Ages and Local Faunas

Since before 1941, North American vertebrate paleontologists have used North American Land Mammal Ages to subdivide Cenozoic geochronologic time. "These time units are applied to nonmarine strata and to the geologic and biologic phenomena represented in these strata (Evernden, Savage, Curtis, and James, 1964, p. 145)." The definition of the Land Mammal Age was first proposed by Wood, and others (the "Wood Committee") in 1941. The term Land Mammal Age refers to a unit of time characterized by a distinct aggregate of fossil land mammals. The fauna definitive of a North American Land Mammal Age is a composite aggregate of fossil land mammals from scattered localities with overlapping faunal composition "inferred to represent a fauna whose members existed during the same restricted geochronologic interval (Evernden and others, 1964, p. 146)."

The Wood committee (1941) proposed the land mammal age as a device for correlating continental Tertiary deposits. The concept was deemed necessary because marine-nonmarine lithologic and faunal interdigitations are rare on this continent, and consequently the European marine State-Age time units could not be extended into the interior of continental North America.

Land Mammal Age correlations are based upon the "stage-of-evolution" of Cenozoic land mammals (Evernden, and others, 1964). This practice is justified by established trends of North American land mammals. These trends include: (1) the rapid rate of morphologic evolution of most of the fossil land mammals; and (2) the extremely rapid dispersal of land mammals as compared to other organisms (Evernden and others, 1964, p. 147). Ideally, each Land Mammal Age represents in bulk a discrete chapter in the evolutionary history of mammals on this continent.

The Hemingfordian Land Mammal Age was proposed by the Wood Committee (1941, p. 12), "based on the Hemingfordian Group including the Marsland and especially the limited or lower Sheep Creek fauna (of Cook and Cook, 1933, p. 38-40), and not on the formation limits as extended upwards (Lugn, 1939." McKenna (1965) and more recently Galusha (1975), have published rigorous reviews of the stratigraphic nomenclature of the Hemingford Group and the Hemingfordian Land Mammal Age. Consequently, this report will not detail the stratigraphic and biostratigraphic modifications of the Hemingford Group and the Hemingfordian Land Mammal Age which have been proposed since the Wood Committee report (1941). This report follows Galusha's (1975) interpretation of the formational composition of the Hemingford Group. Hence, the Hemingfordian Land Mammal Age includes, in ascending order, the faunas of the Marsland, Runningwater, Box Butte, and Sheep Creek Formations (fig. 23).

As originally conceived, most Land Mammal Ages were defined and characterized by a single type-fauna. Continued studies have demonstrated however, that a given Land Mammal Age is in fact defined by a number of local faunas. The concept of the term local fauna has been discussed at length by Tedford (1970). In short, a local fauna is an informal biostratigraphic term for one

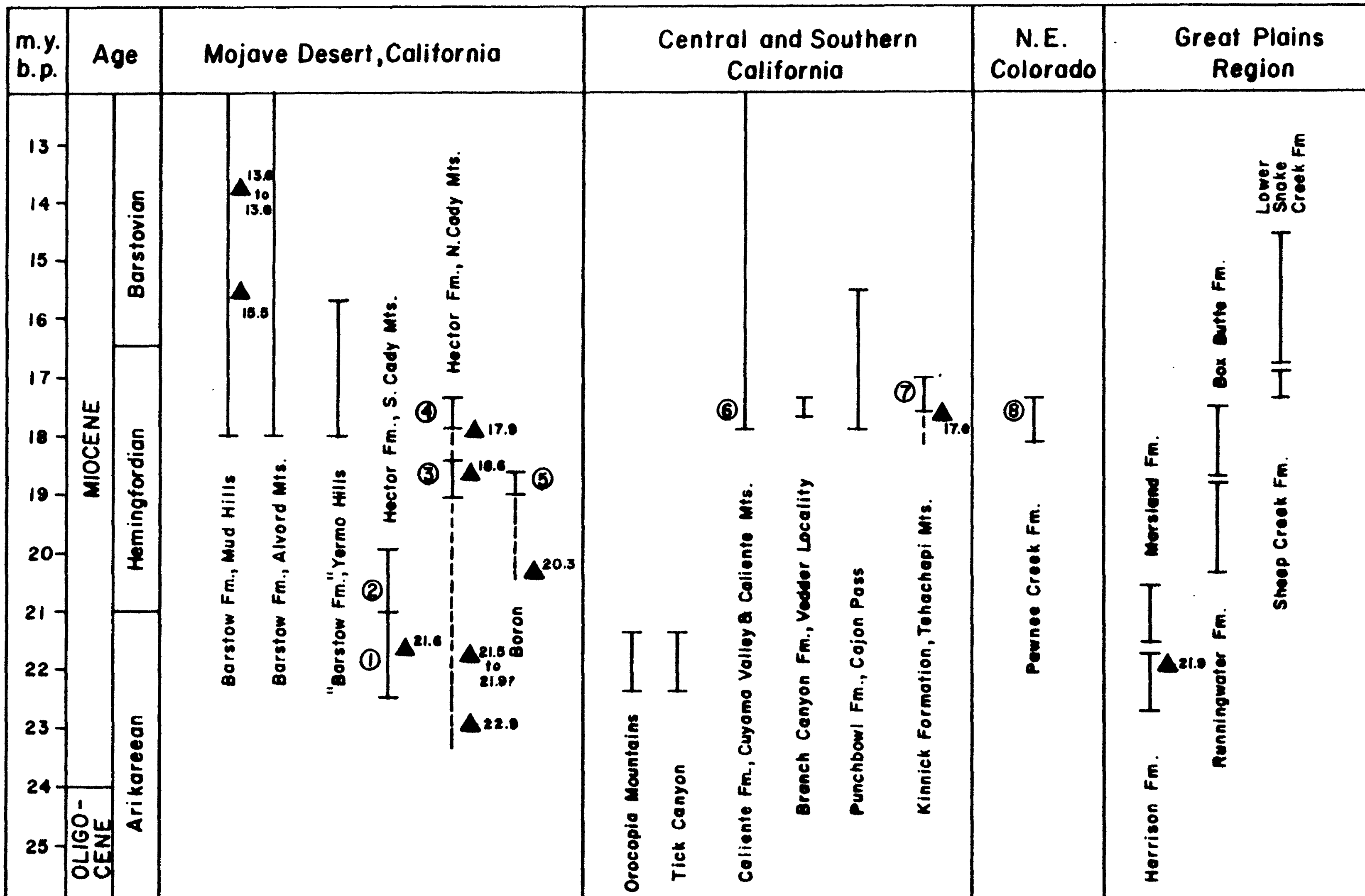

Figure 23.—Stratigraphic relationships between Miocene faunas discussed in this report. ▲ indicates radiometric ages associated with the various faunas; (1) = Black Butte Mine local fauna (l.f.); (2) = Logan Mine l.f.; (3) = lower Cady Mountains l.f.; (4) = upper Cady Mtns. l.f.; (5) = Boron l.f.; (6) = Hidden Treasure Springs l.f.; (7) = Philips Ranch l.f.; (8) = Martin Canyon l.f.
K/Ar dates from: Armstrong and Higgins, 1973; Evernden, and others, 1964; Woodburne, and others, 1974, Moseley, 1978; Lindsay, 1972; and this report. Where necessary, K/Ar ages have been recalculated according to Dalrymple (1979, table 2, p. 559).

species or an aggregate of species "from a single site or a series of closely associated sites having a limited geographic and stratigraphic distribution (Tedford, 1970, p. 683)." The local faunas may be superposed vertically or they may be age equivalent and contain elements of different vertebrate communities. Thus, the local fauna is considered to be the diagnostic part of a Land Mammal Age, and is the working tool of the vertebrate biostratigrapher.

The vertebrate remains from the Hector Foramtion in the northern Cady Mountains are herein subdivided into two local faunas: (1) the Lower Cady Mountains local fauna, and (2) the Upper Cady Mountains local fauna. The Lower Cady Mountains local fauna and the Upper Cady Mountains local fauna are considered to be of middle and late Hemingfordain age, respectively.

The following is a faunal list of the Hector Formation in the northern Cady Mountains:

Lower Cady Mountains local fauna:

Class Mammalia

Merychyus (*Merychyus*) cf. *M.* (*M.*) *calaminthus*
Merychyinae
Aletomerycinae

Upper Cady Mountains local fauna:

Class Mammalia

Proheteromys sulculus
Cf. *Anchitheriomys*? sp.
Tomarctus cf. *T.* *hippophagus*
Merychippus carrizoensis
Cf. *Diceratherium*
"*Miolabis*" cf. "*M.*" *tenuis*
Cf. *Aepycamelus* sp.
Merycodus sp.

Lower Cady Mountains Local Fauna

The Lower Cady Mountains local fauna consists of two artiodactyl subfamilies: (1) the small oreodont subfamily, Merychyinae; and (2) the small paleomerycid subfamily, Aletomerycinae (R.H. Tedford, personal communication, 1977). Bassett and Kupfer (1964, p. 22) mention the presence of camelid remains from their locality KD-1 (= USGS locality M1117), which falls within the stratigraphic range of the Lower Cady Mountains local fauna (plate 3), but they do not give any reference as to where these camelid remains are located. Consequently, the existence of the camelid material has not been verified.

The oreodont subfamily is represented by: (1) limb elements indentifiable only to the subfamily level, and collected from within 50 ft (15 m) of the top of the basalt flow at USGS locality M1117 (R.H. Tedford, personal communication, 1977); and (2) two specimens of Merychyus (Merychyus) cf. M. (M.) calaminthus. UCR 16840, a nearly complete skull and jaws of M. (M.) cf. M. (M.) calaminthus was collected from locality RV-7611, in the southern part of the mapped area (plate 5). A minor fault separates this locality from the basalt unit (with an average absolute age of 18.6 ± 0.2 m.y.b.p.; refer to section on "basalt"), but the locality is estimated to occur 70 to 80 ft (21 to 24 m) below the basalt (plate 2). UCR 16890, consists of the snout region of M. (M.) cf. M. (M.) calaminthus. The specimen was collected in the southwestern part of the mapped area from locality RV-7612 which occurs 25 ft (8 m) above the basalt flow (plates 3 and 5).

The subfamily Aletomerycinae is represented only by limb elements collected from locality M1117, located within 50 ft (15 m) stratigraphically of the top of the basalt flow (plate 3).

The lowest collected fossiliferous interval included within the Lower Cady Mountains local fauna occurs approximately 235 ft (72 m) above a tuff radiometrically dated at 22.9 m.y.b.p. (refer to section on "air-fall tuffs"). the highest collected fossiliferous interval included within the Lower Cady Mountains local fauna occurs approximately 260 ft (79 m) below a rhyolite ash-flow tuff radiometrically dated at 17.9 m.y.b.p. (refer to section on "rhyolite ash-flow tuff").

Within the Mojave Desert province, only one other local fauna contains the same combination of artiodactyl subfamilies as does the Lower Cady Mountains local fauna: the Boron local fauna (Whistler, 1965). In the Boron local fauna, the comparable small merychyine oreodonts are Merychyus (Metoreodon) boronensis and Merychyus (Merychyus) kramerensis. These oredont species occur with the aletomerycine, Aletomeryx. The Boron local fauna is considered to be no younger than early to middle Hemingfordian in age based on the stage of evolution of the Boron oreodonts as compared with oreodont species in the Great Plains region (Whistler, 1965, 1967). The Boron local fauna is younger than the Tick Canyon local fauna and older than the Phillips Ranch local fauna (Whistler, 1965). The Boron local fauna occurs approximately 480 ft (146 m) above a basalt dated at 20.3 m.y.b.p. (Armstrong and Higgins, 1973). The lower Cady Mountains local fauna occurs above and below a basalt with an average age of 18.6 ± 0.2 m.y. I consider the Boron local fauna to be approximately the same age as or slightly older than the lower Cady Mountains local fauna (e.g. middle Hemingfordian).

Merychyus (M.) calaminthus is known from only three other localities in southern California. M. (M.) calaminthus was originally described from the Tick Canyon Formation, Soledad Basin, California (Jahns, 1940). The Tick Canyon Formation is considered to be of late Arikareean or possibly earliest Hemingfordian age (Jahns, 1940; Whistler, 1967). In the Mojave Desert, M. (M.) calaminthus has been recorded from the Black Butte Mine local fauna of the Hector Formation in the southern Cady Mountains (Woodburne and others, 1974). The Black Butte Mine local fauna is considered to be of late Arikareean age based upon: (1) the association of M. (M.) calaminthus with Stenomylus (Stenomylus) cf. S. (S.) hitchcocki, which also is found in the late Arikareean Harrison Formation of Nebraska; and (2) a tuff radiometrically dated at 21.6 m.y.b.p. which is located near the upper boundary of the Black Butte Mine local fauna. The age of the Hector tuff is very close to an age of 21.9 m.y.b.p. determined for a tuff high in the Harrison Formation, but below the Agate Quarry which has yielded remains of S. (S.) hitchcocki (Evernden and others, 1964; and Woodburne and others, 1974). The Black Butte Mine local fauna is overlain by the Logan Mine local fauna of early Hemingfordian age, which has no elements in common with the Lower Cady Mountains local fauna.

Fragmentary remains of M. (M.) calaminthus are also known from the Orocopia Mountains of southern California, and provide a tentative late Arikareean age designation for part of the stratal sequence there (Woodburne and Whistler, 1973). The northern Cady Mountains specimens of M. (M.) cf. M. (M.) calaminthus compare excellently in general morphology with the specimens referred to M. (M.) calaminthus from Tick Canyon, the Orocopia Mountains, and the southern Cady Mountains. The northern Cady Mountains specimens appear to be slightly larger than these other forms, however, which could represent either phenotypic variability or a slightly more advanced state of evolution.

The Tick Canyon local fauna and the Black Butte Mine local fauna have been correlated with the fauna from the Harrison Formaton of the Great Plains region (Whistler, 1967; Woodburne and others, 1974).

As discussed in the systematics portion of this report M. (M.) calaminthus is probably taxonomically synonymous with M. (M.) crabilli. The two taxa overlap in size, although M. (M.) crabilli occurs in the Harrison Formation which is considered to be late Arikareean in age.

Conclusions.--The Lower Cady Mountains local fauna contains merychine oreodonts and aletomerycine paleomerycids. The limited number of specimens and the generally fragmentary nature of the material make age-assignment and comparison with other local faunas difficult. The two subfamilies are found also in the Boron local fauna which is early to middle Hemingfordian in age. The Boron local fauna occurs stratigraphically above the Saddleback Basalt dated at 20.3 m.y.b.p. A basalt of younger age (18.6 ± 0.2 m.y.b.p.) falls within the collected range of the Lower Cady Mountains local fauna. The gross similarities between the two faunas suggest a middle Hemingfordian age for the Lower Cady Mountains local fauna.

A post-Tick Canyon local fauna and post-Black Butte Mine local fauna (post-late Arikareean) age for the Lower Cady Mountains local fauna is suggested by (1) the slightly larger size of the oreodont Merychyus (Merychyus) cf. M. (M.) calaminthus (suggesting a slightly more advanced stage of evolution than typical late Arikareean occurrences of M. (M.) calaminthus); and by (2) the 21.6 m.y.b.p. age of the tuff near the top of the Black Butte mine local faunal interval, as compared with an average age of 18.6 ± 0.2 m.y.b.p. for the basalt within the Lower Cady Mountains local fauna. A middle Hemingfordian age assignment would equate the Lower Cady Mountains local fauna with the middle Hemingfordian Runningwater local fauna. This correlation would extend the range of M. (M.) crabilli (= M. (M.) calaminthus) upward into the middle Hemingfordian. Although all these lines of evidence are not conclusive, there is permissive evidence to suggest that the Lower Cady Mountains local fauna is middle Hemingfordian (early Miocene) in age.

Upper Cady Mountains Local Fauna

The Upper Cady Mountains local fauna consists of nine taxa, including: Proheteromys sulculus, cf. Anchitheriomys? sp., Tomarctus cf. T. hippophagus, Merychippus carrizoensis, cf. Diceratherium sp., "Miolabis" cf. "M." tenuis, cf. Aepycamelus sp., and Merycodus sp. These nine taxa were collected from thirteen localities (plates 4 and 5) spanning 292 ft (89 m) of the upper unit of the Hector Formation. In plate 4, the vertical distribution of the fossil localities is shown relative to two measured sections of strata included within the upper unit of the Hector Formation. The known occurrences of each taxon also are plotted on plate 4.

Fossils have been found from approximately 125 ft (38 m) above the fault which cuts out the base of the upper unit (Fault C, plate 1) to approximately 48 ft (15 m) below the top of the formation (plate 4). Approximately 50 percent of all described specimens, including eight of the nine taxa represented, were collected from a single quarry, RV-6631 (=M1128=KD-2 Quarry of Bassett and Kupfer, 1964). RV-6631 occurs 242 ft (74 m) above the base of the upper unit of the Hector Formation. The second most prolific quarry, producing 22 percent of the described specimens and including two taxa, is RV-7615. RV-7615 represents the highest fossiliferous horizon in the Hector Formation and occurs 417 ft (127 m) above the base of the upper unit (plate 4).

Other authors (e.g., Tedford, 1966; Woodburne, and others, 1974) have noted a strong compositional correlation between Hemingfordian faunas of the Mojave Desert region and those of the Great Plains region. This correlation is further strengthened by the Upper Cady Mountains local fauna. Only two taxa range throughout the fossiliferous interval of the upper unit of the Hector Formation, namely Merychippus carrizoensis and "Miolabis" cf. "M." tenuis. Merychippus has attained a stage of evolution comparable to that of M. primus from the Sheep Creek Formation of the Great Plains (see systematics section, this report). "Miolabis" cf. "M." tenuis compares very favorably with the type of "Miolabis" tenuis which also was collected from the Sheep Creek Formation. The Sheep Creek Formation is late Hemingfordian in age, which strongly suggests a late Hemingfordian age for the Upper Cady Mountains local fauna.

Merychippus cf. M. primus and "Miolabis" tenuis aff. also occur in the the Box Butte Formation which underlies the Sheep Creek Formation in the Great Plains region (Galusha, 1975, p. 54). In the Box Butte, these two taxa are found with Tomarctus sp., Aepycamelus cf. A. priscus, and Merycodus sp. the Upper Cady Mountains local fauna is not correlated with the Box Butte fauna, however, because the equid, camelids and canid from the Box Butte are smaller and appear to be at an earlier stage of evolution than their respective counterparts in the northern Cady Mountains.

An older age for the Upper Cady Mountains local fauna is suggested by the castorid, cf. Anchitheriomys? sp., which is found in the middle Hemingfordian (late Arikareean of Wilson, 1960) Martin Canyon local fauna of northeastern Colorado. The taxonomic relationship of cf. Anchitheriomys? sp. to other castorids, its comparative stage of evolution, and its chronologic range are poorly understood at present, however, which makes satisfactory correlation difficult. Proheteromys sulculus also is found in the Martin Canyon local fauna, but in addition occurs in the Vedder locality fauna of California. The Vedder locality fauna also contains specimens of Merychippus carrizoensis (Munthe, 1979) which suggest a late Hemingfordian age for this fauna and support a late Hemingfordian age assignment for the Upper Cady Mountains local fauna.

A younger (Barstovian) age is suggested by the canid. The canid compares most favorably with Tomarctus hippophagus, which was collected from the Barstovian-aged Lower Snake Creek beds of the Great Plains region. Since size is the primary criterion for this taxonomic assignment, however, correlation based on canid appears tenuous.

The rhinoceros, cf. Diceratherium sp., the camelid, cf. Aepycamelus sp., and the antilocaprid, Merycodus sp. are only generally useful for correlation. Cf. Diceratherium sp. suggests a Hemingfordian age for the Upper Cady Mountains local fauna. Cf. Aepycamelus sp. appears to be closest in stage of evolution to the Sheep Creek aepycamelines. Merycodus sp. could have either late Hemingfordian or Barstovian affinities.

The Upper Cady Mountains local fauna as a whole compares most favorably with the late Hemingfordian assemblage from the lower Sheep Creek beds of the Great Plains.

Within the Mojave Desert region, several fossil localities have produced taxa correlative with the Upper Cady Mountains local fauna (fig. 23). The lowest fossiliferous interval of the Barstow Formation in the Mud Hills (the Owl Conglomerate member of Dibblee, 1968) and in the Alvord Mountains (Lewis, 1968) has produced Merychippus carrizoensis (= tehachapiensis). The lowest fossiliferous interval of the Barstow Formation in the Yermo Hills (Odessa Canyon member of McCulloh, 1952) has produced abundant remains of Merychippus carrizoensis in conjunction with "Miolabis" cf. "M." tenuis (M.O. Woodburne, personal communication, 1977). These three localities underlie fossiliferous sequences containing Barstovian faunas, and are considered to be late Hemingfordian in age. The Yermo Hills sequence is unique, however, in that the upper part of the sequence contains Merychippus carrizoensis associated with more typical Barstovian forms such as Merychippus stylodontus (M.O. Woodburne, personal communication, 1977). This fact suggests that M. carrizoensis may not have been confined to the late Hemingfordian, and thus cannot be used as a positive indicator of late Hemingfordian age. The Yermo Hills occurrence, however, represents the only known situation in which M. carrizoensis may not be associated with Hemingfordian-age faunas in the Mojave Desert.

Several California fossil localities outside the Mojave Desert region also have produced taxa correlative with the Upper Cady Mountains local fauna (fig. 23). In the Cajon Pass area, San Bernardino County, California, M. cf. M. carrizoensis (= tehachapiensis) occurs alone in Unit 2 of the Punchbowl Formation, and with other typically late Hemingfordian elements in the lower portion of Unit 3 of the Punchbowl Formation (Woodburne and Golz, 1972). In the Phillips Ranch fauna of the Kinnick Formation, Kern County, California, M. carrizoensis (= tehachapiensis) occurs with other Hemingfordian taxa includinng Cynorca sociale (Woodburne, 1969; Buwalda, 1916). The Caliente Formation, Caliente Range, San Luis Obispo County, California has produced a late Hemingfordian fossil assemblage including the type of M. carrizoensis (Dougherty, 1941; Repenning and Vedder, 1961). The Caliente Formation extends southeast from the Caliente Range into the Cuyama Valley and the Cuyama Badlands, Ventura County, California. James (1963) recognized one local fauna of Hemingfordian age, the Hidden Treasure Spring fauna (and three faunas of Barstovian age), in the Badlands area. The Hemingfordian fauna includes Merychippus carrizoensis. The Vedder locality from the predominantly marine Branch Canyon Sandstone, Santa Barbara County, California has also produced a late Hemingfordian fauna containing M. carrizoensis and Proheteromys sulculus (Munthe, 1979; Lindsay, 1974; Repenning and Vedder, 1961; specimens in the collections of UCMP AND USNM).

A late Hemingfordian age for the Upper Cady Mountians local fauna is supported by the 17.9 m.y.b.p. date which was obtianed from the rhyolite ashflow tuff unit immediately underlying the upper unit of the Hector Formation (refer to section on rhyolite ashflow tuff unit). Although this date sets a maximum age limit on the Upper Cady Mountains local fauna, no minimum age can be designated.

Conclusions.--The taxon shared by the majority of late Hemingfordian vertebrate faunas in the Mojave Desert and elsewhere in central and southern California is Merychippus carrizoensis (= tehachapiensis). Although this taxon is not definitive of late Hemingfordian time, where it is found it does strongly infer a late Hemingfordian age. At present only one possible exception is known in the Mojave Desert, the Yermo Hills, where M. carrizoensis coexisted with taxa generally considered to be of Barstovian age.

In summary, the Upper Cady Mountains local fauna is assigned a late Hemingfordian age based upon: (1) the close relationship of the Upper Cady Mountains local fauna to the late Hemingfordian lower Sheep Creek fauna of Nebraska; (2) the strong ties of the Upper Cady Mountains local Fauna to other late Hemingfordian local faunas of the Mojave Desert region and elsewhere in central and southern California; (3) the 17.9 m.y.b.p. date which occurs stratigraphically below the fauna.

SUMMARY

The northern Cady Mountains sequence of the Hector Formation contains approximately 1250 ft (381 m) of interbedded clastic, carbonate, and volcanic rocks of early Miocene age. The rocks were deposited in a lacustrine-fluvial-alluvial setting on the southern flank of the Barstow Basin -- a major east-west-trending structural trough which dominated the regional physiography from latest Oligocene through at least middle Miocene time. The base of the formation is not exposed in the study area, but the Hector can be seen to unconformably overlie an older volcanic and granitic terrain which is exposed south and west of the study area.

Sedimentary rocks of the Hector Formation are characterized by two facies: (1) a coarse-grained facies which includes an alluvial-fan complex and a fluvial complex; and (2) a fine-grained lacustrine facies. The alluvial-fan complex contains poorly sorted, texturally immature pebble-bearing sandstone and pebble to boulder conglomerate. The fluvial complex consists of poorly sorted tuffaceous mudrock, siltstone, sandstone, and conglomerate. The coarse-grained facies exhibits channeling, mud-flows, cross-bedding of both fluvial and aeolian character, and rocks that are interpreted to be dilute mud-flow deposits. The fine-grained lacustrine facies consists of laminated to thick beds of tuffaceous claystone, mudrock, siltstone, and sandstone with minor conglomerate, limestone, and water-lain tuff. The fine-grained facies is zeolitized locally.

Intermittent volcanism accompanied deposition of the sedimentary rocks. Volcanic rocks which are intercalated with the sedimentary strata include: (1) an olivine-augite basalt flow; (2) a welded rhyolite ash-flow tuff; and (3) several air-fall tuffs which occur at intervals throughout the section. K/Ar radiometric ages were determined for three of the volcanic units: (1) 22.9 $\pm$ 0.4 m.y. for a biotite air-fall tuff near the base of the exposed section; (2) 18.6 $\pm$ 0.2 m.y. for the basalt flow; and (3) 17.9 $\pm$ 0.3 m.y. for the rhyolite ash-flow tuff.

Fossil mammals collected from numerous localities within the study area are grouped into two local faunas: the Upper Cady Mountains local fauna and the Lower Cady Mountains local fauna. The middle and latest Hemingfordian ages assigned to the these two local faunas agree well with the radiometric ages obtained from the volcanic units.

The Hector Formation is unconformably overlain by four unnamed Tertiary and Quaternary alluvial units. These units are, in ascending order: (1) an older fanglomerate and gravel unit; (2) an older gravel unit; (3) an older alluvium unit; and (4) a younger alluvium unit. These units are presumed to be late Tertiary through Quaternary in age.

The dominant structural trends displayed in the study area include: (1) a poorly defined east-trending and east-plunging syncline which deforms rocks of the Hector Formation; and (2) both major and minor, generally north-trending, moderate to high-angle normal faults which disrupt both the Hector Formation

and the older fanglomerate and gravel unit. At least two episodes of faulting are present. The earliest episode of faulting occurred after folding of the Hector Formation but prior to deposition of the older fanglomerate and gravel unit. This earlier episode is presumed to be late Miocene or early Pliocene in age. The later episode of faulting occurred after deposition of the older fanglomerate and gravel unit but prior to the older gravel and older alluvium units. This later episode is presumed to be Quaternary (?Pleistocene) in age.

SYSTEMATIC PALEONTOLOGY

Terminology

The following abbreviations will be used in the Systematic Paleontology portion of this report:

UCR = Department of Earth Sciences, University of California, Riverside
UCMP = University of California, Museum of Paleontology, Berkeley
USNM = National Museum of Natural History, Smithsonian Institution, Washington, D.C., collections presently housed at the U.S. Geological Survey, Menlo Park
LACM = Los Angeles County Museum of Natural History
AMNH = American Museum of Natural History, New York
CIT = California Institute of Technology, collections now housed at LACM
AP = Anteroposterior diameter
TR = Transverse diameter
CH = Crown height
PD = Proximal-distal length
Ix/ = Upper incisor
I/x = Lower incisor
C = Canine
Px/ = Upper premolar
P/x = Lower premolar
Mx/ = Upper molar
M/x = Lower molar
dP =Deciduous premolar
L = Left
R = Right

All measurements are in millimeters.

Order RODENTIA
Family HETEROMYIDAE
Subfamily HETEROMYINAE
Genus PROHETEROMYS Wood, 1932
Proheteromys sulculus Wilson, 1960

Synonomy: *Proheteromys sulculus* Wilson, 1960, University of Kansas Paleontological Contributions, Vertebrata no. 7, p. 75.
Proheteromys sulculus Wilson. Lindsay, 1974, PaleoBios no. 16, p. 13-16, figs. 6, 7.

Type: University of Kansas Museum of Natural History no. 10203, a left mandible bearing P/4-M/2, from the Pawnee Creek Formation, Quarry A, Martin Canyon local fauna, Logan County, northeastern Colorado.

Age: The holotype was collected from rocks considered to be Arikareean in age by Wilson (1960, p. 75), but which Lindsay (1974, p.13) infers to be Hemingfordian. Fossil remains referred to *P. sulculus* also have been collected from the Hemingfordian-age Vedder fauna of the Branch Canyon Formation, Santa Barbara County, California (Lindsay, 1974).

Generic and Specific characters: Wood (1935, p. 166) lists the following characteristics as diagnostic of the genus *Proheteromys*: "Cheek teeth bilophodont and in about the same stage of development as in *Mookomys*, and likewise based upon a primarily sextitubercular pattern; upper incisors asulcate; heteromyine pattern developing in cheek teeth; P/4 quadritubercular; posterior cingula on lower and anterior cingula on upper teeth."

Wilson (1960, p. 75) gives the following specific diagnosis for *Proheteromys sulculus*:

> "Size approximately that of *Proheteromys matthewi*, *P. thorpei*, or *Mookomys formicorum*. Upper incisor weakly sulcate. Incipient J-pattern in P4/, lacking accessory cuspules in protloph. M3/ having cusps surrounding a central basin. Anterior end of masseteric crest relatively distinct. Lower incisor somewhat flattened on anterior surface. P/4 having stylids usually present, mesoconid well-developed, and principal external cusps closer together than those of internal pair. Lower molars having weak hypostylids, altogether absent on M/3. M/1 usually, M/2 less frequently, having H-pattern."

Referred specimens: The UCR specimens are all isolated teeth except for UCR 17861, a fragmentary right mandible with P/4 and M/2, and the alveolus for M/1. The isolated teeth include UCR 16944, LM1/; UCR 16967, RM/2; UCR 16968, RP4/; UCR 16970, RP/4; UCR 16965, RI/1; UCR 16943, LI1/; and UCR 16969, RI1/. UCR 16965 was collected from locality RV-7153; all other specimens were collected from locality RV-6631.

Description: (Dental terminology after Lindsay, 1972): UCR 16968 is a right P4/ which is missing its roots and has a slight break at the juncture between the hypostyle and hypocone. the protoloph is single and cusped and transversely oval, with no accessory cuspules. The metaloph is three-cusped, with an anteroposteriorly lengthened hypostyle. There is strong suggestion of a posterior cingulum, although the break occurs at this point. The protocone and metaloph have a sub-medial union.

The upper molar is transversely oval in occlusal outline, and the width is greater than the length. UCR 16944 is a slightly worn, low-crowned, left M1/. The tooth is bilophodont, with three cusps on each loph. The roots are long and separate. The protoloph and metaloph are subequal in size. The protoloph is straight, while the metaloph is curved. The anterior cungulum is continuous and runs between paracone and protostyle anterior to the protcone. The transverse valley is narrow, shallow and straight, closing along the lingual border by union of hypostyle and protostyle. The tooth is slightly narrower than P4/ (see Table 1), and compares favorably with M1/ of P. sulculus as figured by Lindsay (1974, p. 14, fig. 6).

The lower premolars have an obovate occlusal outline, with length greater than width. UCR 16970 is a slightly worn, low-crowned right lower premolar which is missing its roots. The tooth is bilophid, with two main cusps (protoconid and protostylid) and a small medial anteroconid on the protolophid, and two main cusps (metaconid and hypoconid) and a small hypostylid on the labial order of the metalophid. The protolophid is narrower than the metalophid. The protostylid is smaller than the protoconid, and the protoconid is slightly anterior relative to the prototstylid. The transverse valley is deepest on the lingual side. P/4 of UCR 17861 is more worn than UCR 16970, but otherwise identical.

The lower molars have an oval occlusal outline, with width greater than length. UCR 16967 is a moderately worn, low-crowned, right lower molar. It is broken on its labial border and is missing its roots. The tooth is bilophid, with three cusps each on the hypolophid and metalophid. the labial portions of the hypostylid and protostylid have been removed, but the hypostylid appears to be smaller than the protostylid. The anterior cingulum is continuous from the protostylid to the metaconid, with no apparent separation anterior to the protoconid. The transverse alley is straight, relatively open, and narrows labially. The tooth is approximately the same dimensions as 16944 (LM1/), and morphologically identical to the RM/2 of UCR 17861. These two lower molars compare most favorably with M/2 of P. sulculus as figured by Lindsay (1974, p. 15, fig. 7).

Three isolated incisors are also questionably referred to P. sulculus. UCR 16943 is a left upper incisor, UCR 16969 is a right upper incisor, and UCR 16965 is a right lower incisor. The upper incisors are definitely sulcate, which is typical of both P. sulculus and Perognathus, and separates these from Cupidinimus and Trogomys (Lindsay, 1972; Wilson, 1960). The sulcate pattern on the incisors of P. sulculus is light and shallow, however, compared to Perognathus, and the incisors are slightly larger than the closest forms of Perognathus. Although Wood (1935) considers asulcate upper incisors to be characteristic of the genus, Wilson (1960, p. 78) assigned sulculus to Proheteromys because all other morphologic "features of P. sulculus are those cited by Wood (1935) as characteristic of the Heteromyinae or found in the Heteromyinae when not characteristic." Due to the size of the incisors, the weakly sulcate pattern, and the presence of P. sulculus in the Upper

Cady Mountains local fauna, these incisors are questionably referred to that species.

Comparison with related species: Proheteromys sulculus has been described from the Quarry A fauna in Colorado (Wilson, 1960), and from the Vedder fauna in California (Lindsay, 1974). Specimens of P. sulculus from the northern Cady Mountains are indistinguishable from specimens of the Vedder fauna. Specimens from Quarry A in Colorado have slightly smaller P4/, M1/, and P/4, than do the northern Cady Mountains forms (Wilson, 1960, p. 78, and table 1 of this report); otherwise, specimens from the two areas appear to be identical. P. sulculus is larger than P. floridanus from the Hemingfordian Thomas Farm fauna of Florida; possibly the relatively small size of the latter is a more primitive feature. P. magnus from the deposits at Fullers Earth Company Mine, Midway, Florida, and P. maximus from the Barstovian portion of the Caliente Formation faunal sequence, California, are both much larger than P. sulculus. P. matthewi, from the upper Rosebud of South Dakota, agrees in size, but lacks accessory cuspules on P/4 (Wilson, 1960).

Morphologically, P. sulculus closely resembles Mookomys altifluminus of the Vedder fauna, Perognathus furlongi of the Barstovian portion of the Barstow Formation (Lindsay, 1972, 1974), and Trogomys Reeder from the Tick Canyon fauna of California (Reeder, 1960). Wood (1931, 1935) considered Mookomys as the stem of the Perognathinae, and Proheteromys as the stem of the Heteromyinae. Wilson (1960, p. 78), on the other hand, proposed that these two subfamilies are not clearly separable at this point in time (Hemingfordian) or stage of evolution. Both Mookomys and Proheteromys share characters of the subfamily Heteromyinae (Wood, 1931, 1935; Lindsay, 1974), and Lindsay (1974) places both genera in the same subfamily (Heteromyinae). In addition, Lindsay (1974, p. 12) suggested Mookomys altifluminus, albeit an earlier population of M. altifluminus, probably gave rise to P. sulculus. M. altifluminus differs from P. sulculus in several significant features including: (1) smaller size; (2) morphology of P4/4; and (3) occlusal outline of molars and premolars. The morphology of the upper incisors of M. altifluminus is unknown.

Although P. sulculus, Perognathus furlongi and Trogomys are morphologically similar, there are significant differences between them. Trogomys differs from P. sulculus in having: (1) smaller size; (2) a median rather than a sub-median union of protoloph and metaloph on P/4; (3) asulcate upper incisors; (4) lower crowned cheek teeth; and (5) no accessory cuspules on P/4. Perognathus furlongi is much smaller than P. sulculus, has lower crowned cheek teeth, and has no accessary cuspules on P/4.

Conclusions: The heteromyid specimens from the northern Cady Mountains compare excellently both in size and morphology with specimens of Proheteromys sulculus from the Vedder fauna (Lindsay, 1974), and are assigned to that species.

Table 1.--Comparison of *Proheteromys sulculus* from the Northern Cady Mountains with the Holotype and Referred Specimens (measurements in millimeters; all dimensions are greatest occlusal)

	P4/	M1/	P/4		M/2		
UCR No.	16968	16944	16970	17861	16990	16967	
AP	1.60	1.05	1.00	1.09	0.99	1.05	Upper Cady Mountains
Tr	1.40	1.30	1.00	1.15	0.99	1.10	l.f.: UCR specimens
AP	1.0-1.4	1.0	0.8-0.9		0.9-1.1		Range *P. sulculus*
Tr	1.1+-1.3	1.2	0.8-1.0		1.0-1.2		(Wilson, 1960, p. 78)
AP	1.24-1.53	0.93-1.11	1.07-1.23		1.00-1.17		Range *P. sulculus*
Tr	1.37-1.53	1.28-1.45	1.00-1.22		1.24-1.33		(Lindsay, 1974, p. 9)

Family CASTORIDAE
Genus ANCHITHERIOMYS Roger, 1885
cf. Anchitheriomys? sp.
(Figures 24, 25, 26, 27)

Referred specimens: USNM 184102, consisting of two isolated teeth, LM1/ or 2/ and RM/2, and associated fragmentary skeletal elements including a right ulna, a right radius, left and right distal tibias, a fragmentary left femur, an atlas, and parts of three ribs; and USNM 184103, consisting of a right femur. 184102 was collected from locality M1119; 184103 was collected from locality M1128.

Description: (Terminology after Stirton, 1935): USNM 184102 consists of a left upper molar, and a right lower molar and associated skeletal elements (figs. 24, 27). The teeth are extremely large and heavily worn, to a point where the internal wall is much longer than the external wall. The upper molar has one internal fold of enamel (the hypoflexus), the corresponding groove or stria on the side of the tooth is quite short in the existing stage of wear. The mesoflexus is represented by an isolated fossette (the mesofossette). The presence of only one posterior fossette suggests that this tooth is an M1/, rather than an M2/, which exhibits both a metafossette and submesofossette (Wilson, 1960, p. 66, fig. 70c). However, it is possible that the upper molar of the northern Cady Mountains specimen is actually an M2/ and that greater wear has caused the submesofossette and metafossette to merge.

The lower molar of Anchitheriomys? sp. figured by Wilson (1960, p. 66, fig. 68b) is only slightly worn, and therefore is difficult to compare with the specimen from the northern Cady Mountains. However, the lower molar of USNM 184102 is nearly identical to the left M/2 of the type of Monosaulax senrudi (Wood, 1945, p.3) from the Fighting Buttes locality, Carter County, Montana. It exhibits the same simple, nearly transverse fossettids (fig. 24) and the same squared-up occlusal outline. As in the M/2 of M. senrudi, the California specimen has four fossettids (hypofossettid, parafossettid, mesofossettid and metafossettid). M/1 of M. senrudi, however, has two posterior fossettids (submesofossettid and metafossettid) instead of only one. The specimen from the Northern Cady Mountains compares closely in size with both M. senrudi and Anchitheriomys? sp. from Quarry A, Martin Canyon local fauna, Pawnee Creek Formation, Colorado (table 2).

Like the teeth, the skeletal elements (ulna, radius, distal tibia, femurs, ribs and atlas) are also quite large in size. These elements are several times times larger than comparative elements of Monsaulax pansus from the Hemingfordian(?) Stewart Springs local fauna of Nevada. USNM 184103, a right femur, is questionably referred to Anchitheriomys? sp. because it compares very favorably in size with the femur collected in association with the teeth (USNM 184102).

Comparisons with related species: Wilson (1960, p. 66-68) discusses in great detail the relationship of Anchitheriomys? sp. from the Hemingfordian-age (late Arikareean of Wilson, 1960) Martin Canyon local fauna to other castorids. Hence, only a brief summary will be given here.

Figure 24.--Cf. Anchitheriomys? sp., USNM 184102. (a) Left M1/ or M2/, and (b) right M/2; occlusal view, scale approximately 4x.

Figure 25.--Cf. Anchitheriomys? sp., USNM 184102. (a) Left M1/ or M2/, anterior view; (b) right M/2, posterior view; scale approximately 4x.

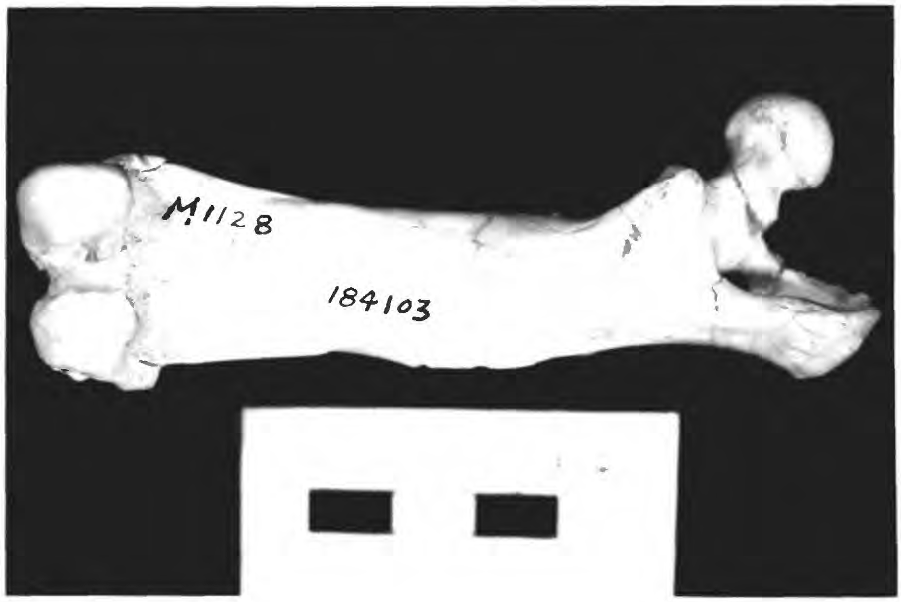

Figure 26.--Cf. Anchitheriomys? sp., USNM 184103. Right femur, posterior view.

Figure 27.--Cf. Anchitheriomys? sp., USNM 184103. Right femur, anterior view.

TABLE 2.--Measurements of the Teeth of cf. Anchitheriomys? sp. and of the Holotype of Monosaulax senrudi (measurements in millimeters; all measurements are greatest occlusal dimension)

	This paper cf. Anchiteriomys? USNM 184102		Wilson, 1960 cf. Anchitheriomys?		Wood, 1945 Monosaulax senrudi
	LM1/ or 2/	RM/2	KU 10173	KU 10175	
M1/ AP	5.1		5.5		
Tr	5.2		7.0		
M2/ AP			5.5		
Tr			6.8		
M/2 AP		5.7		5.8	6.1
Tr		6.85		6.1	6.7

As noted by Wilson (1960, p. 66), Anchitheriomys? sp. from the Martin Canyon local fauna "represents a species larger than any other known from the North American Miocene save Monosaulax senrudi, Hystricops venustus, and Amblycastor fluminus." Hystricops venustus and Amblycastor fluminus are both much younger than Anchitheriomys? sp. The name Monosaulax senrudi was assigned by Wood (1945) to a specimen from Montana of approximately the same size and dentitional morphology as Wilson's Anchitheriomys? sp. Wood did not feel comfortable in assigning the specimen to Monosaulax, and probably should not have done so on such scanty evidence. Wood acknowledges this by stating (p. 5) that his specimen might be "a specialized Monosaulax, or a primitive Amblycastor, or a borderline species, or a new genus related to both..." Wood placed the age of his specimen at "about Barstovian" (p. 5).

Wilson (1960, p. 68) noted the striking similarity of his specimen to Monosaulax senrudi, but also saw a strong connection with Amblycastor. Wilson tentatively referred his specimen to Anchitheriomys?, however, "although the species probably does not represent the genus strictly speaking".

Conclusions: The specimens from the northern Cady Mountains strongly resemble both Anchitheriomys? sp. and Monosaulax senrudi as figured and described by Wilson (1960) and Wood (1945), respectively. These three forms probably represent a new genus closely related to Amblycastor or possibly a new species within the genus Amblycastor. The material is still very fragmentary, however, and until more complete specimens are obtained, a new taxon should not be erected. Consequently, the specimens from the northern Cady Mountains are tentatively referred to Anchitheriomys? sp. as discussed and figured by Wilson (1960).

Order CARNIVORA
Family CANIDAE
Genus TOMARCTUS Cope, 1873
Tomarctus hippophagus (Matthew and Cook, 1909)

Synonomy: *Tephrocyon hippophagus* Matthew and Cook, 1909, AMNH

Bulletin, v. 26, p. 373, fig. 4

Type: AMNH no. 13836, a right mandible with C, P/2-4, M/1-2, collected from the lower Snake Creek Beds, Sioux County, Nebraska.

Age: The holotype is part of the Lower Snake Creek fauna of upper Miocene (Barstovian) age.

Generic and Specific comments: The genus *Tomarctus* is characterized by a bicuspid heel and a large, compressed trigonid (relative to *Canis*) on the lower carnassial. "The practical distinction of this genus *Tephrocyon* = *Tomarctus* from *Canis* in the lower jaws, which are most frequently found, is the invariable presence of a well-developed paraconid on m_2 (Matthew, 1918, p. 188)." According to Matthew and Cook (1909), *Tomarctus hippophagus* from the Barstovian Lower Snake Creek fauna of Nebraska is smaller in size and has somewhat more slender proportions than *T. brevirostris* from the Barstovian Pawnee Creek beds of northeastern Colorado.

Tomarctus cf. *T. hippophagus*
(Figures 28, 29)

Referred specimens: UCR no. 15983, a left mandible containing P/2 to M/2; UCR no. 13632, a right mandible containing P/2 to M/2; and UCR no. 15982, a right M/1. All specimens were from locality RV-6631.

Description: The teeth of UCR 15983 (fig. 28) are fully emerged, unbroken, and at an early stage of wear. The premolars are oval in occlusal outline. The premolars show no tendency to slant toward the posterior margin of the jaw, but are oriented at a slight angle to the long axis of the jaw. Each premolar (P/2-4) has an anterior accessory cuspule, a principal cusp slightly anterior to the center of the tooth, a posterior accessory cuspule, and a posterior cingular cusp. All cusps lie in a straight line except on P/4, where the posterior cingular cusp lies just lingual of the center line of the tooth. The premolars increase in size posteriorly.

The trigonid of M/1 is large, with a well-developed metaconid. The hypoconid and entoconid of M/1 are subequal, with the entoconid perhaps slightly higher. Measured across the protoconid, the trigonid is narrower than the talonid. M/2 also has a biscuspid heel. On M/2 the trigonid is more compressed than on M/1, but the paraconid is still distinct. The hypoconid and metaconid are essentially equal in size, and the talonid is much narrower than the trigonid. There is an antero-external cingulum on M/2 that extends from the paraconid to the protoconid.

Figure 28.--Tomarctus cf. T. hippophagus, UCR 15983. Left mandible with P/2 to M/2; lingual view.

Figure 29.--Tomarctus cf. T. hippophagus, UCR 13632. Right mandible with P/2 to M/2; labial view.

The anterior mental foramen is below the anterior root of P/2 and the posterior mental foramen lies below the median portion of P/3. The teeth (especially the premolars) are not well spaced, and tend to overlap slightly. The ventral border of the mandible is not completely preserved, and the masseteric fossa is not preserved, so the convexity of the posteroventral margin is unknown.

The carnassial from this mandible (UCR 15983) and the single carnassial (UCR 15982) were collected from the same quarry (RV-6631), are identical in appearance, are very close in size, are at the same stage of wear, and represent opposite sides of the tooth row. They are definitely of the same species and possibly represent the same animal.

UCR 13632 (fig. 29), a right mandible which has P/2 to M/2, is slightly more robust than the other two specimens, both in tooth dimensions and in mandible size (table 3). The teeth of UCR 13632 are fully emerged, and, except for P/3 and some patches of enamel loss on M/1 and M/2, are unbroken. The teeth are at an early stage of wear, and are morphologically indistinguishable from the other specimens. This suggests that the larger specimen falls within the morphologic variability of the species.

Comparisons with related species: The measurements (table 3) of the three Riverside specimens range from slightly smaller to slightly larger than those of the type of *T. hippophagus* (AMNH no. 13836) which was incorrectly synonymized with the larger Pawnee Creek form *T. brevirostris* by Matthew (1924) (R.H. Tedford, personal communication, 1975). The Riverside specimens are larger than the measurements of the type of *T. optatus* from the Nebraska Sheep Creek beds of Hemingfordian age, and are smaller than the measurements of *T. brevirostris* (AMNH 18244, table 3). The UCR specimens compare favorably with the figure of the type of *T. hippophagus* (Matthew and Cook, 1909, fig. 4).

Comparisons were made with the type specimen of *T. rurestris* (the genotype of "*Tephrocyon*", from the Mascall fauna of Oregon, Condon Museum of Geology, University of Oregon, no. 23077). UCR 15983 is more slender, and the M/1 is shorter in anteroposterior diameter, which results in a shorter anteroposterior measurement of the tooth row (P/2-M/2). UCR 13632 is also more slender than 23077, but M/1 is slightly longer in anteroposterior diameter than is 23077, and has approximately the same anteroposterior measurement of the tooth row. The UCR specimens have definite anterior cuspules on the premolars, whereas none appear on *T. rurestris*. P/2 of *T. rurestris* is smaller than P/2 of both UCR 15983 and 13632. In addition, the metaconid on M/1 is more distinct and better developed on the UCR specimens. The anteroexternal cingulum on M/2 is better developed on *T. rurestris*. In *T. rurestris*, the anterior mental foramen lies beneath the posterior root of P/1, and posterior mental foramen lies beneath the juncture of P/3 and P/4. The cusps of all premolars are in a straight line on *T. rurestris* and, although P/2 overlaps slightly on P/3, and P/4 overlaps slightly on M/1, P/3 (unlike the Riverside specimens) does not overlap P/4. Despite these differences, it is obvious that the Cady Mountains form is closely related to *T. rurestris*.

TABLE 3.--Measurements of the Holotype* of *Tomarctus* cf. *T. hippophagus*, of Referred Specimens, and of Comparative Specimens of *Tomarctus brevirostris* and *T. Optatus* (measurements in millimeters)

	T. optatus'	*T. brevirostris*	**T. hippophagus*	*T.* cf. *T. hippophagus*		
	AMNH	AMNH	AMNH		UCR	
	18916	18244	13836	15983	15982	13632
P/2 AP	7.2	7.7	8.4	8.05		8.00
Tr				4.20		4.25
P/3 AP	8.4	9.3	9.3	9.05		9.00
Tr				4.50		
P/4 AP	10.4	12.3	11.6	10.80		11.50
Tr				5.50		5.75
M/1 AP	17.8	21.5	19.7	18.65	18.95	20.70
Tr				7.45	7.50	8.50
M/2 AP	9.2	11.3	10.3	10.40		10.50
Tr				6.95		6.95
P/2-M/2 AP				55.55		
M/1 AP heel	5.4	6.1	5.6	5.65	5.70	
M/1 Tr heel	7.5	8.4	8.6	7.45	7.50	8.50
M/2 AP heel	3.4	4.6	4.3	4.15		4.00
M/2 Tr heel				5.45		5.50
M/1 Tr				7.25	7.35	7.60
mand. depth below protoconid M/1	16.7	20.9	24.5	18.80		
mand. depth below P/4				8.90		

'From Downs (1956, Table 5, p. 234).

T. temerarius (Leidy) of the Barstovian-age Niobrara River fauna (Leidy, 1858; Matthew, 1924) is smaller in size than the Cady Mountains form, but has approximately the same proportions of M/2 to M/1, and distinct anterior cuspules on the premolars. *T. robustus* Green of the Clarendonian-age Ricardo fauna (Green, 1948) is much larger and more massive; it exhibits a greater thickness of the teeth and has anterior cuspules on the premolars. *T. euthos* (McGrew) of the Clarendonian Burge fauna has no lower jaw associated with the type, but the skull is much larger than that of *T. hippophagus* (McGrew, 1935). A mandible referred to *T. euthos* by Macdonald (1960) shows a longer M/2 in proportion to M/1 than the Riverside specimens, and premolars with anterior cuspules. *T. paulus* Henshaw of the Barstovian-age Tonopah fauna is much smaller, and has no anterior cuspules on the premolars. *T. confertus* Matthew of the Barstovian-age Lower Snake Creek fauna (Matthew, 1924) is smaller, being closer in size to *T. paulus* and *T. temerarius*. *T. confertus* has anterior cuspules on the premolars.

Downs (1956) suggests that *T. optatus* and *T. brevirostris*, which are morphologically very similar, are probably synonymous. He bases this partly on measurements which he took on the type of *T. optatus* and referred specimens of *T. brevirostris*, including the type of *T. hippophagus*. Downs states (p. 233): "If all three jaws, nos. 18244, 13836 [the type of *T. hippophagus*] of *T. brevirostris*, and no. 18916 of *T. optatus*, are placed in series, *T. optatus* falls between the two specimens 18244 and 13836 in nearly every dimension." However, the measurements (table 5, p. 234; confirmed by R. H. Tedford, personal communication, 1975) show that *T. optatus* is actually smaller in all but one respect (the anteroposterior diameter of M/3) than *T. brevirostris*. This fact would seem to cast serious doubt as to the validity of Downs' synonymy of *T. brevirostris* and *T. optatus*.

Conclusions: The specimens from the northern Cady Mountains are the largest representatives of *Tomarctus* known from the Hemingfordian. The Hemingfordian form closest in size to the northern Cady Mountains specimens in *T. optatus*. Of the two Barstovian species, the Northern Cady Mountains specimens most closely resemble *T. hippophagus*. *T. hippophagus* and the Cady Mountains specimens fall between *T. brevirostris* and *T. optatus* in size. Morphologically, however, the three species are very similar. Thus, the northern Cady Mountains canid may be considered either: (1) a small, early version of *T. brevirostris*; (2) an older representative of *T. hippophagus*; or (3) a large variant of *T. optatus*. Since the morphological similarities are so strong between the three forms, size being the only distinguishing characteristic in the lower jaw, the author chooses tentatively to refer the northern Cady Mountains specimens to *T. hippophagus* which is of approximately the same size.

Order PERISSODACTYLA
Family EQUIDAE
Subfamily EQUINAE
Genus MERYCHIPPUS Leidy, 1857
Merychippus carrizoensis Dougherty, 1940
(Figures 30, 31, 32, 33)

Synonomy: *Merychippus carrizoensis* Dougherty, 1940, Carnegie Institute of Washington Publication no. 514, p. 130.

Merychippus tehachapiensis Buwalda and Lewis, 1955, U.S. Geological Survey Professional Paper 264-G, p. 147-152.

Type: LACM (CIT) no. 2552, a fragmentary left maxillary with M1-3/ collected from the Caliente Formation, Caliente Mountains, San Luis Obispo County, California (Dougherty, 1940, p. 130 and pl. 4, figs. 1, 1a).
Age: The holotype is from the middle Miocene (Hemingfordian) part of the Caliente fauna (Dougherty, 1940, p. 128).

Generic and specific characters: The genus *Merychippus* is characterized by a subhypsodont to hypsodont dentition, transversely tapering from the broader base to the narrower crown, and with some degree of curvature of the ectoloph. The protocone is either connected or isolated from the protoconule; when isolated, the protocone has a spur. The styles tend to widen toward the base of the tooth. There is an incomplete connection of the crochet with the protoconule in unworn teeth. The crown height should exceed 20 mm at the mesostyle in unworn upper cheek teeth (Stirton, 1939).

According to Dougherty (1940, p. 130), *Merychippus carrizoensis* is characterized by hypsodont upper cheek teeth with a crown height slightly less than in *M. primus* (Osborn), but greater than in *M. gunteri* Simpson. In size, *M. carrizoensis* is close to *M. primus*. The protocone is attached firmly to the protoconule almost immediately after wear is initiated. Cement coating is thin although the fossettes are largely filled. The post-fossette is rarely plicated, while the pre-fossette exhibits two or three plications with one-quarter wear. The lower cheek teeth show moderately complex enamel folds, and are poorly cemented (although more so than are the uppers). There is a distinct separation of the metastylid on the molars.

Referred specimens: Specimens referable to *M. carrizoensis* are of two forms or varieties: variety A is a form generally smaller than the type of *M. carrizoensis*; variety B is a form slightly larger than the type. Specimens referred to variety A are the following: UCR nos. 16955, 16956, 16957, 16958, 16910, 16911, and 16914 from locality RV-7615, and 16901, from locality RV-7613. These specimens are all isolated right and left lower cheek teeth. In addition, referred specimens include UCR no. 16315, a jaw fragment with left I/1-2, P/2-3, right I/1-3, P/2-M/2, collected from locality RV-7514; and UCR nos. 16949, 16950, 16951, 16952, 16953, 16954, 16967, 16968, 16912, 16913, and 16769, right and left isolated upper cheek teeth, collected from locality RV-7615.

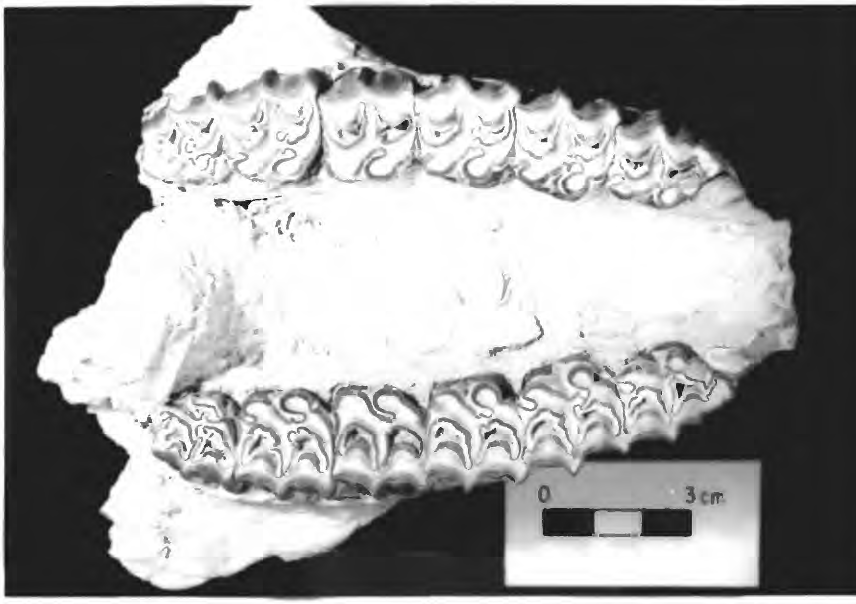

Figure 30.--*Merychippus carrizoensis*, UCR 16029. Palate with left and right P/1 to M/3 and associated premaxilla with left I1/ and alveoli for left I2-3/, right I1-3/, and right canine; occlusal view.

Figure 31.--*Merychippus carrizoensis*, UCR 16029. Palate; right labial view.

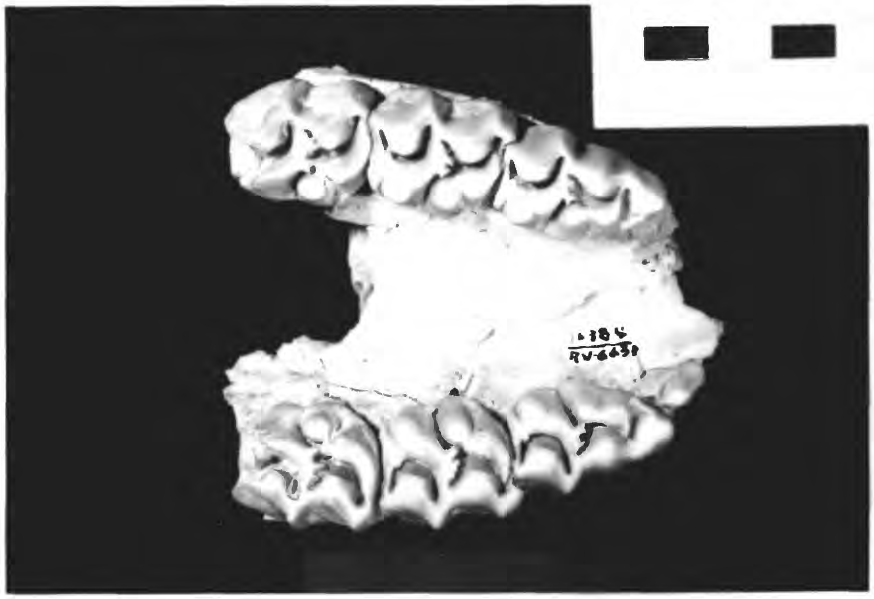

Figure 32.--*Merychippus carrizoensis*, UCR 15984. Deciduous palate with right dP2-4/ and left dP1-4/; occlusal view.

Figure 33.--*Merychippus carrizoensis*, UCR 16315. Mandibles with left I/1-2, P/2-3, right I/1-3, P/2 to M/2; occlusal view.

Specimens referred to variety B are the following: UCR 16029, a palate with left and right P1/-M3/ and associated premaxilla with left I1/ and alveoli for left I2-3/, right I1-3/, and right canine; UCR 15984, a palate with right dP2-4/ and left dP1-4/; USNM 184104, the anterior portion of a lower jaw with left and right I/1-3 and C, and associated left mandible with P/2-M/2; UCR 16390, a left mandible with P/2-M/3; UCR 16368, a right mandible fragment with P/2-4; and UCR 16370, an isolated left M2/ or M2/. The above specimens were collected from locality RV-6631 (M1128).

Description: Specimen descriptions are subdivided into descriptions of variety B and descriptions of variety A.

Upper dentition of variety B is best represented by UCR 16029 (figs. 30, 31). UCR 16029 has a fully erupted hypsodont dentition, moderately worn. The protocone is elliptical, and is broadly connected to the protoconule. The teeth have a relatively thin coating of cement, and the fossettes are thickly lined but not filled with cement. The fossette walls show progressive simplification in enamel pattern with increased wear. The cheek teeth have at least a single, and often a double pli caballin fold, either incipient or well developed. The labial faces of paracone and metacone show a faint but definite, median rib. The mesostyle is prominent and widens at the base. The protoconule and metaconule are subequal to the protocone and hypocone. The post-fossette joins with the posterior border of the tooth via the hypoconal groove until the tooth has experienced approximately one-third wear. The post-protoconal valley unites with the prefossette through approximately one-third wear in P2/-M2/, but probably never unites in M3/. The prefossette is still connected in P3/, just closed in P2/, and completely closed in the rest of the cheek teeth. The post-protoconal valley is lined and sometimes filled with cement.

UCR 16370 is a slightly worn M1/ or M2/, and shows suggestions of three or more plications in the posterior enamel border of the prefossette, and at least one in the anterior enamel border of the postfossette. The palate (UCR 16029) shows at least 50 percent wear and subsequently the enamel pattern is quite simple, with one plication in the posterior enamel border of the prefossette of P3/, none in P4/, none in M1/, two in M2/, and three in M3/ (with the least wear).

The crowns of the cheek teeth are most strongly curved in the upper one-third. The metaconule-hypocone and protoconule-protocone are very loph-like in the slightly worn tooth (UCR 16370). UCR 16029 and 16370 are slightly larger than the type. The teeth are small, with the anteroposterior diameter of the cheek teeth ranging from 16.10 to 20.45 mm, transverse diameter ranging 16.35 to 18.90 mm, and crown height ranging from 13.80 to 17.00 mm (table 4). The transverse diameter is smaller than the anteroposterior diameter in P2/, essentially equal to the anteroposterior diameter in P3/, and greater than the anteroposterior diameter in P4/ and M1-3/. The crown height is less than the transverse diameter in all cheek teeth except M3/ (showing the least wear). Where the crown height is less, the difference between the transverse diameter and the crown height ranges from 0.65-6.50 mm.

The deciduous dentition (UCR 15984; fig. 32) shows completely erupted right dP2-4/ and left dP1-4/. These are brachy-hypsodont, only slightly to moderately worn, and covered with either a very thin layer of cement or none at all. The hypocone of dP4/ is unworn. The milk teeth are consistently larger in anteroposterior diameter than are the permanent premolars, but are consistently smaller in transverse diameter. The crown height measurements of dP1/ and dP4/ are larger than those of permanent premolars, while the measurements of dP2-3/ are smaller. This, however, is due only to the stage of wear. The folding of the enamel on the fossette walls is much more complex than in the permanent premolars (UCR 16029), but the deciduous teeth are at an earlier stage of wear. Unlike the adult teeth, dP2-4/ exhibit lingual cingular cusps: on dP2/, the cusp lies between the base of the protocone and the base of the metaconule; on dP3/, there are two cingular cusps, one between the base of the protocone and the protoconule, and one between the base of the protocone and the hypoconule; on dP4/ the only cingular cusp lies between the base of the protocone and the protoconule. There are strong antero-internal cingula on dP3-4/ near the base of the protoconule. The labial faces of paracone and metacone are flat, and show no development of a median rib.

The lower dentition of variety B is represented by three partial mandibles. UCR 16376 contains a full complement of lower incisors and canines plus a left mandible with P/2-M/2. UCR 16368 is a right mandible fragment which contains P/2-4. UCR is a left mandible fragment with P/2-M/3. All three specimens have fully erupted, heavily worn teeth. All three specimens are small, close in size, and slightly larger than the type of M. carrizoensis. The lower teeth are more heavily cemented than are the upper. Due to extreme wear, the enamel pattern is presently confined to the outer borders and invaginations of the teeth. The teeth are worn down past the base of the internal groove between the metaconid and metastylid, and therefore cannot be compared on the basis of enamel pattern with the type. However, the small size, low crown height and relatively prismatic, rather than anteroposteriorly elongate, nature of the cheek teeth compare favorably with the type as pictured by Dougherty (1940).

Specimens referable to variety A are generally smaller in size and crown height than the type of M. carrizoensis. Variation within the sample does occur, however, and variety A approaches variety B in size and crown height (table 4). Tooth morphology of variety A is indistinguishable from variety B on any one tooth character (except size), although some tendencies seem to be stressed in various specimens referable to the smaller form. In the upper cheek teeth, these include: (1) the tendency to lose even the suggestion of a medial rib on the labial surfaces of the paracone and metacone, much as in the deciduous palate described above; (2) the tendency of the protocone to be more anteroposteriorly elongate and more elliptical; (3) in about 50 percent of the individuals, the tendency of the prefossette to remain connected with the post-protoconal valley for a longer period of time; (4) in about 50 percent of the individuals, the tendency of the post-fossette to remain connected with the posterior border of the tooth for a longer period of time; and (5) the tendency for protocone to become larger than the hypocone. It should be noted here, however, that statistically I am dealing with a very small sample size.

Table 4.--Measurements of the Holotype* of <u>Merychippus</u> <u>carrizoensis</u> and of Referred Specimens
(measurements in millimeters; ( ) = approximate measurement)

	Buwalda and Lewis 1955			Dougherty, 1940		
	CIT 4919	CIT 4920	UCR 16029	UCR 15984	CIT nos.+	
P1/ AP			9.65			
Tr			6.00			
CH			3.65			
P2/ AP	18.9		20.45		21.0	
Tr	14.2		16.35		16.5	(2553)
CH	16.0		15.70			
P3/ AP			18.75		16.8	
Tr			18.80		19.5	(2558)
CH			17.00			
P4/ AP	15.7	15.8	18.65		16.9	
Tr	16.9	17.1	18.90		18.8	(2560)
CH	16.0	(14.0)	12.50			
M1/ AP	15.7	15.0	16.90		*16.6	
Tr	17.5	16.5	10.30		18.0	(2552)
CH	13.9	15.7	13.80			
M2/ AP		14.2	17.55		*16.0	
Tr		15.7	19.75		19.5	(2552)
CH		20.0	(14.00)			
M3/ AP			16.10		*14.3	(2552)
Tr			16.35			
CH			(16.65)			
dP1/ AP				10.10		
Tr				5.35		
CH				6.45		
dP2/ AP				23.60		
Tr				14.80		
CH				9.20		
dP3/ AP				19.90		
Tr				16.70		
CH				9.80		
dP4/ AP				20.15		
Tr				16.75		
CH				14.60		
P1/-M3/			109.60			
P1/-P4/			61.10			
dP1/-dP4/				66.85		

+ specimen numbers arranged vertically below

In the lower teeth of variety A, the only noticeable tendency, other than decreased size, is a relative transverse compression of M/3. The incomplete jaw referred to variety A (UCR 16315; fig. 33), lacks M/3, and therefore cannot be compared on that basis with the other small, but isolated, specimens. The small jaw compares excellently in size and in general morphology with a specimen of *M. primus* in the collections of the USGS at Menlo Park. The UCR specimen is very worn, however, so detailed comparisons cannot be made.

Comparison with related species: The UCR specimens were compared with the type of *M. carrizoensis* and with a large collection of topotypes and other referred specimens of *M. carrizoensis* in the collections of the USGS, Menlo Park, California. In addition, the specimens were compared with specimens and a cast of the type of *M. primus* from the Sheep Creek beds of Nebraska. Finally, they were compared with a cast of the type and referred specimens of *M. tehachapiensis*, and with larger species of *Merychippus* from the collections at UCR, LACM and the USGS, Menlo Park. The small size, low crown height, simple pattern, and attached protocone very early in wear, set the UCR specimens apart from *M. relictus*, *M. stevensi*, *M. stylodontus*, *M. californicus*, *M. seversus*, *M. sumani*, and *M. intermontanus*: forms typically found in Miocene faunas of the West Coast and the Great Basin. *M. primus* of the Sheep Creek beds is very close in size, morphology and crown height to the UCR forms. *M. primus*, however, has the protocone isolated for a longer period of time before it becomes attached to the protoconule. A section was made through an unworn upper cheek tooth of *M. primus* at approximately one-half the distance between the base and the crown. The resulting pattern showed a broad connection of protocone and protoconule, and a much simplified fold pattern in the enamel of the fossette borders. At that stage of wear (approximately 50 percent), it is nearly impossible to distinguish the species of *M. primus* and *M. carrizoensis* on the basis of dentitional morphology. However, the two species can be separated by differences in facial morphology where such material is preserved.

The UCR specimens most closely resemble *M. carrizoensis* which the author considers synonomus with *M. tehachapiensis*. The measurements of the Cady Mountains specimens of variety B were generally larger than the type of *M. carrizoensis* and specimens of variety A generally smaller than the type, but the teeth are close enough morphologically that I believe this difference reflects variation rather than differences at the specific level.

Discussion: *Merychippus carrizoensis* was described in 1940 by Dougherty on the basis of a small collection of specimens from the Caliente Formation, Caliente Mountains, California. Due to the limited number of specimens, little variation in size or crown height was noted. Buwalda and Lewis (1955) described *M. tehachapiensis* on the basis of a small number of specimens from the Phillips Ranch Fauna (Kinnick Formation), Tehachapi Mountains, California. Neither species has any related skull material. Buwalda and Lewis (1955) noted in their discussion that the cheek teeth of *M. tehachapiensis* are morphologically similar to *M. carrizoensis* and "range from somewhat smaller to about the same size in plan, but are from 10 to 15 percent higher-crowned, and with a protocone further forward than in *M. carrizoensis* Dougherty (p. 149)." Subsequent collecting from the Caliente Range and Cuyama Valley Badlands (Repenning and Vedder; 1961, James, 1963; Munthe, 1979) has provided specimens of *M. carrizoensis* which show a range of variation in crown height and protocone position that overlaps with *M. tehachapiensis*. James (1963, p. 13) informally noted the obsolescence of the name *M. tehachapiensis* by referring to the Phillips Ranch form as "*Merychippus carrizoensis*". James has not as yet published the second part of his Cuyama Valley faunal study, that part dealing with the "macrofossils", but the synonomy of *M. tehachapiensis* and *M. carrizoensis* was formalized by Munthe (1979).

The author has viewed specimens of *M.* "*tehachapiensis*" and *M. carrizoensis* from the collections of U.C. Berkeley, LACM, and the USNM (at the Geological Survey, Menlo Park) and agrees that the two forms should be synonymized. Since the name *Merychippus carrizoensis* has precedence, the UCR specimens are referred to that species.

Family RHINOCEROTIDAE
Diceratherium March, 1875
Cf. Diceratherium sp.
(Figures 34, 35)

Referred specimens: UCR 16960, a fragmentary right upper cheek tooth; UCR 16964, the labial wall of an upper cheek tooth; and USNM 184105 a fragmentary left mandible containing parts of M/1-2? UCR 16960 and 16964 were collected from locality RV-7153; USNM 184105 was collectd from locality M1128.

Description and discussion: Three specimens of a small rhinocerotid were collected in the northern Cady Mountains. The lower cheek teeth (figs. 34, 35) have moderately high, relatively narrow crowns with nearly parallel transverse crests. These teeth exhibit (1) moderate wear; (2) rugosely striate enamel; and (3) strong internal and external cingula. Both the lower cheek teeth and the upper cheek teeth lack cement. The lower cheek teeth (M/1-2?) are approximately the same size as M/1-2 of Diceratherium cookei figured by Peterson (1960b). M/2? is approximately 29.8 mm long at the occlusal surface, and approximately 21.2 mm. wide at the base.

The specimens are too fragmentary for positive assignment at the generic level. However, in size and general tooth morphology, they most closely approach Diceratherium as described by Marsh (1875) and Peterson (1906a,b).

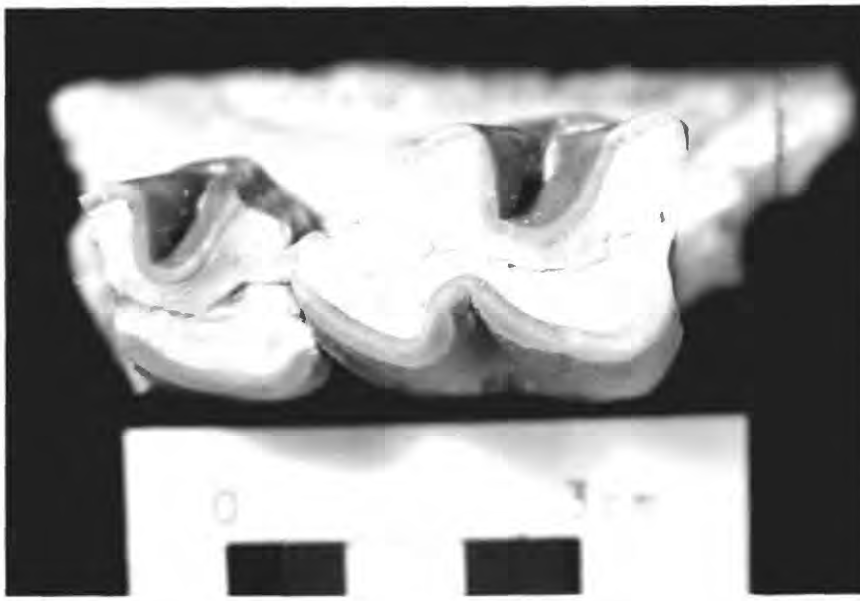

Figure 34.--Cf. Diceratherium sp., USNM 184105. Left mandible with fragmentary M/1-2?; occlusal view.

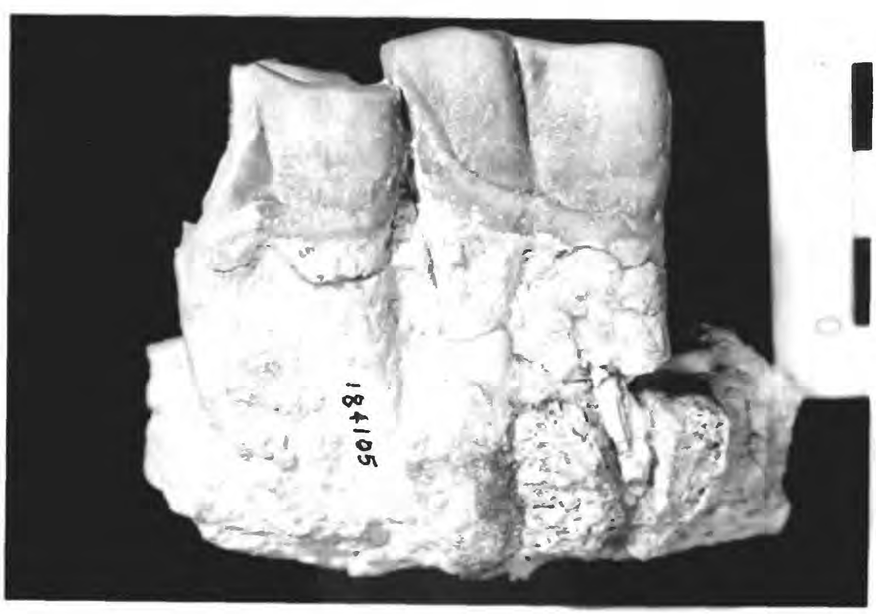

Figure 35.--Cf. Diceratherium sp., USNM 184105. Left mandible; labial view.

Order ARTIODACTYLA
Family MERYCOIDODONTIDAE
Subfamily MERYCHYINAE
Genus MERYCHYUS Leidy, 1858
Merychyus (Merychyus) calaminthus Jahns, 1940

Synonomy: Merychyus calaminthus Jahns, 1940, Carnegie Institute of Washington, Publ, no. 514, p. 187.
Merychyus crabilli Schultz and Falkenbach, 1947, American Museum of Natural History Bulleting, vo. 88, art. 4, p. 189, figs, 1, 6, 13-17.

Type: CIT no. 1382, a partial skull with P1-4/, M1-3/ (combination of both sides) collected from the Tick Canyon formation, Los Angeles County, California.

Age: The holotype is a part of the Tick Canyon fauna of early Miocene (late Arikareean or earliest Hemingfordian) age.

Generic and specific characters: (For a discussion of the origin of the generic name, see Matthew, 1901, p. 418-419; Schultz and Falkenbach, 1947, p. 171-174). Schultz and Falkenbach (1947, p. 171) characterize the genus

Merychyus as follows:

"SKULL: Small, basal length ranging from 123 mm. to 178 mm.; mesocephalic; supraoccipital wings fan-shaped, widely spread, and incorporated in the occipital flare, but the flare not so pronounced as in the genus Ustatochoerus; exoccipital pits roundish in outline but not so large as in Ustatochoerus; base of paroccipital process not completely incorporated in the fan-shaped region as in Ustacochoerus or Merychyus (Metoreodon). . .; sagittal crest prominent but not high; brain case inflated; zygomatic arch light to medium light; lacrimal fossa prominent in Harrison forms and shallow in later species; prelacrimal vacuity present; infraorbital foramen either above posterior portion of P3/ or above P4/; nasals slightly retracted, extending posterior to the anterior of the orbits; premaxillae fused for a short distance; paroccipital process wide transversely, narrow anteroposteriorly, and long vertically; occipital condyles medium in size, but varying greatly in dimensions; bullae with various degrees of flattening.

MANDIBLE: Small; moderately deep for size of skull; inferior border nearly straight with a slight downward curve just posterior to M/3; condyle of moderate size; symphysis prominent, posterior point below region of P/3-P/4.

DENTITION: Advanced brachyodont to sub-hypsodont; I1/1 and I2/2 approximately equal in size, with I3/3 larger; superior canines vary in size from small to large; P/1 may be small or large."

The species Merychyus (Merychyus) calaminthus is characterized by Jahns (1940, p. 187) but revised slightly by Whistler (1967, p. 3). According to Whistler's amended diagnosis of the type specimen (CIT 1382), M.(M.) calaminthus is slightly smaller in size than M. (Merychyus) crabilli Schultz and Falkenbach of the Great Plains. The skull has a deep antorbital fossa, but a small prelacrimal vacuity (when present). The depth of the malar bone is moderate, and there is but a single large infraorbital foramen above P4/. The dentition is mesohypsodont with a straight and closely spaced superior tooth row. P1-2/, however, are set at a definite angle to the alveolar border. P3-4/ have only moderately reduced anterior lophs, and all superior premolars have fairly complicated patterns. The external styles of the superior molars are moderately prominent.

In addition, Jahns and Whistler noted the presence of a small lingual spur projecting into the fossette in P4/. Woodburne, Tedford, Stevens, and Taylor (1974) in a description of a partial skull of this species collected from the southern Cady Mountains suggest that the species typically exhibits: (1) a concave nasal profile; (2) cingula present only on the anterior and posterior margins of P4/; and P1-3/ (as opposed to only P1-2/) definitely inclined to the alveolar border.

Merychyus (Merychyus) cf. M (M.) calaminthus
(Figures 36-41)

Referred specimens: UCR 16840, a complete skull with right C1/, P1/-M3/, left P2/-M3/, and mandibles with full dentition but missing the ascending rami; and UCR 16890, a maxillary fragment with right I3/, C, P1-2/, left I3?/, P1/; and a mandible fragment with right I/3/ P/2-3, left I/3, C, P/1. UCR 16840 was collected from locality RV-7611, and UCR 16890 was collected from locality RV-7612.

Description: UCR 16840 is a nearly complete skull, minus only the premaxillary with the upper incisors and the auditory bullae (figs. 36 through 39). The dentition is fully mature and extremely worn, so that all trace of the patterns on the premolars and molars, exept for a trace of a pattern on M3/, has been removed (fig. 37).

The specimen is consistent with the generic characteristics. The skull and jaws (figs. 40, 41) agree closely in every aspect of size and general proportions with the type of Merychyus (Merychyus) calaminthus. UCR 16840 differs from the type in that it contains a double infraorbital foramen above the posterior root of P3/, instead of only a single foramen above P4/. The teeth are too worn to show whether or not there were originally (1) a complicated premolar pattern, (2) a lingual spur on P4/, or (3) moderately reduced anterior lophs on P3-4/. The specimen does show P1-3/ definitely overlapping and inclined to the alveolar border with the rest of the superior tooth row being quite straight. The skull is lightly constructed, the nasal profile is distinctly concave, the malar depth is moderate, the antorbital fossa is typically deep, and a small prelacrimal vacuity is present. Cingula are absent except on the anterior and posterior borders of P4/.

UCR 16890 consists only of the snout region with well worn teeth. The teeth compare excellently with those of UCR 16840.

Figure 36.--Merychyus (Merychyus) cf. M. (M.) calaminthus, UCR 16840. Skull; dorsal view.

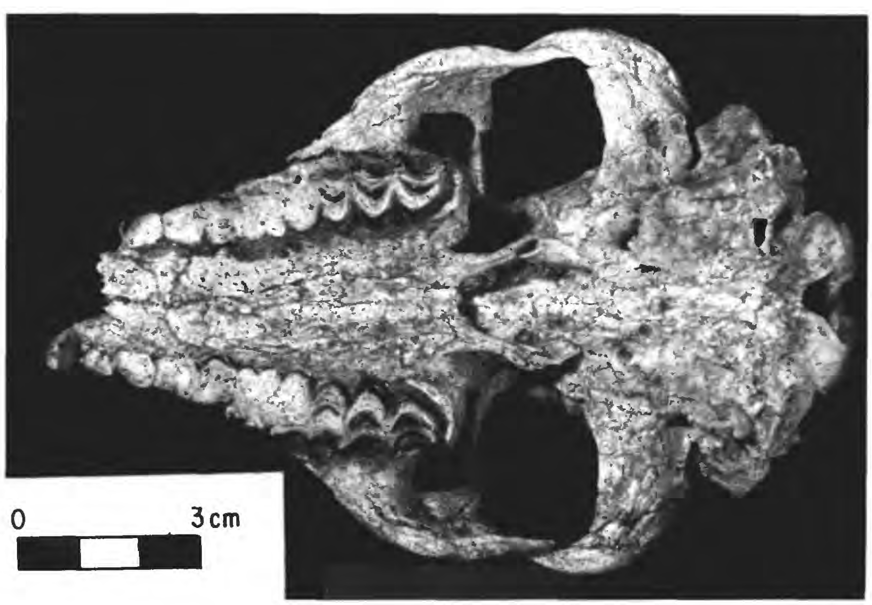

Figure 37.--Merychyus (Merychyus) cf. M. (M.) calaminthus, UCR 16840. Skull; ventral view.

Figure 38.--*Merychyus* (*Merychyus*) cf. *M*. (*M*.) *calaminthus*, UCR 16840. Skull; right lateral view; scale approximately X.85.

Figure 39.--*Merychyus* (*Merychyus*) cf. *M*. (*M*.) *calaminthus*, UCR 16840. Skull; occipital view.

Figure 40.--*Merychyus* (*Merychyus*) cf. *M*. (*M*.) *calaminthus*, UCR 16840. Lower jaws; occlusal view.

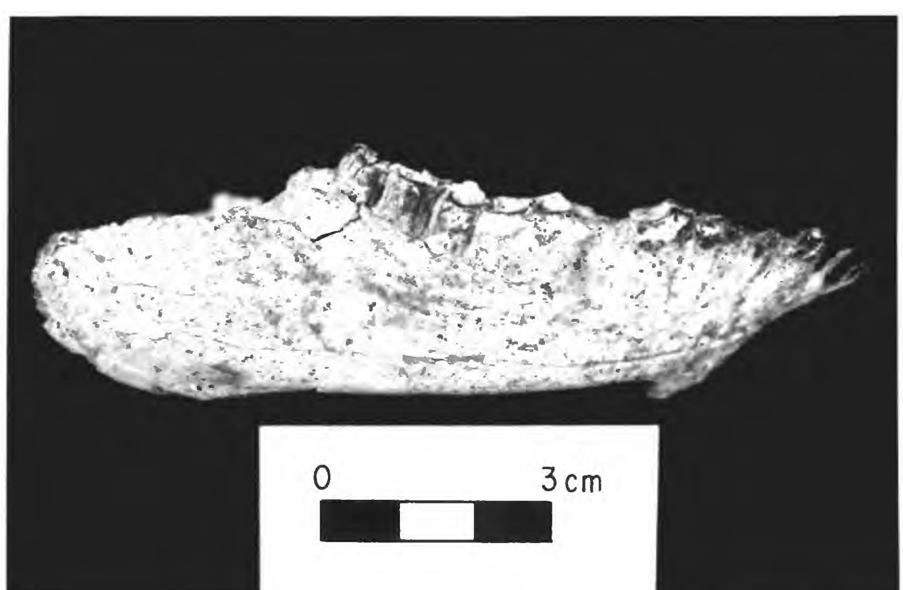

Figure 41.--*Merychyus* (*Merychyus*) cf. *M*. (*M*.) *calaminthus*, UCR 16840. Lower jaws; right labial view.

Table 5.--Comparative Measurements of the Holotype* of Merychyus (Merychyus) calaminthus and of Referred Specimens, and of the Type of M. (M.) crabilli (all measurements in millimeters)

	This Paper		Whistler, 1967		Woodburne and others, 1974	Schultz and Falkenbach, 1947
						M. (M.) crabilli
	UCR 16840		LACM 1383	LACM 1382*	UCR 10914	USNM 1-1-7-33
	Left	Right				
Facial length, C to ant. rim of orbit		50.0	(58)			
Malar depth below orbit	14.30	16.4	13.2	10.0	11.9	15.
Palate width at M1/	21.65		21.3	16.1		
C-M3/ AP		67.63	(78)			72
P1/-M3/ AP		62.35	--	--	63.5	67
P1/-P4/ AP		27.27	28.0	--	29.0	28.5
M1/-M3/ AP	35.90	35.20	36.0	30.6	37.8	40.5
P4/ AP"	7.60	8.30	7.0			
Tr"	8.93	9.14	9.1			
CH"	6.20	6.40	10.0			
M3/ AP	18.15	17.10	15.5	13.6	17.1	14
Tr	12.45	12.45	11.8	12.0	13.5	
CH at mesostyle		13.07	11.0	(12)		
M2/ CH at mesostyle	6.85	6.65	8.7	8.0		
Skull length along dorsal midline	128.55					

TABLE 5.--Continued

	This Paper		Whistler, 1967	Woodburne and Whistler, 1973		Woodburne and others, 1974	Schultz and Falkenbach, 1947 *M. (M.) crabilli*
	UCR 16840		LACM 1342	LACM 27026		UCR 14971	FAM 44458
	Left	Right		Left	Right		
Skull length along basal midline	115.80						
P/1-M/3 AP	62.25	66.15					71
P/1-M/4 AP	27.20	27.00					31
M/1-M/3 AP	(38.80)	(39.00)	35.8				40
M/3 AP	(20.45)	(20.30)		18.8	18.45	18.5	
Tr	8.60	8.70			9.85		
CH at mesostylid		8.95					
M/2 AP	10.85	10.85	10.0		12.4		
Mand. depth below ant. edge of M/3	20.83	19.55					26.5

" = maximum

( ) = approximate measurement

Comparisons with related species: Measurements of the skull and dentition are listed in table 5. The measurements of UCR 16840 are extremely close to those of both M. (M.) calaminthus and M. (M.) crabilli of the same age, but residing in the Great Plains region. It has been suggested by Schultz and Falkenbach (1947, p. 190) and Woodburne, Tedford, Stevens and Taylor (1974, p.19), that M. (M.) crabilli is a geographic variant of M. (M.) calaminthus. M. (M.) crabilli was proposed by Schultz and Falkenbach (1947) because: (1) they regarded the type specimen of M. (M.) calaminthus to be an immature individual, and (2) because they found it difficult to compare the fragmentary remains of the California specimens (holotype and referred specimens) with the excellent remains of a large number of individuals which they found in the Midwest. Whistler (1967) showed the holotype of M. (M.) calaminthus to be an adult individual as Jahns (1940) had described it. Whistler's work, plus the description of additional material of M. (M.) calamainthus from the Mohave Desert region (Woodburne, Tedford, Stevens, and Taylor, 1974; Woodburne and Whistler, 1973; this paper) would seem to suggest that the synonomy of the two forms (M. (M.) calaminthus and M. (M.) crabilli is valid.

Merychyus calaminthus (= crabilli) is consistently smaller than M. arenarum, M. (M.) minimus, and M. siouxensis of the Great Plains region. The snout of M. (M.) calaminthus is shorter than that of M. arenarum, as are the nasals. The bullae of M. calaminthus are well inflated, slightly flattened, and relatively large for the size of the skull, as compared to those of M. arenarum. The skull and mandible of M. calaminthus have a lighter construction overall than do those of M. arenarum and M. minimus, and a much lighter construction than M. siouxensis. The lower edge of the ramus of M. calaminthus is nearly straight as compared to the more convexly shaped ramus of M. arenarum. The ramus of M. calaminthus shows a slight, gradual increase in depth posteriorly, but is shallower than M. arenarum and M. minimus.

Conclusions: The small oreodont from the northern Cady Mountains is represented by ony two specimens, one of which is very fragmentary. The other specimen is a nearly complete skull and rami, but the dentition is so worn that it is of little help in a taxonomic assignment. Consequently, the oreodont is assigned to Merychyus (Merychyus) cf. M. (M.) calaminthus (= crabilli, as discussed above), based upon the small size, light construction, and morphology of the skull.

Family ANTILOCAPRIDAE
Subfamily MERYCODONTIDAE
Genus MERYCODUS Leidy, 1854

Merycodus sp.
(Figure 42)

One specimen of a large antilocaprid was found in the northern Cady Mountains. The specimen, USNM 184106 (fig. 42), is a partial right mandible containing the roots of P/2-4, and fragmentary M/2-3. The specimen was collected from USGS locality M1118.

The antilocaprid specimen from the northern Cady Mountains compares very favorably in size, shape of the mandible, and depth and curvature of the mandible with a specimen of *Merycodus sabulonis* from the late Hemingfordian Sheep Creek beds of Nebraska, as figured by Matthew and Cook (1909, p. 411). The teeth of the northern Cady Mountains specimen are relatively higher crowned and more robust, however, as compared to the Sheep Creek form. The northern Cady Mountains specimen also compares very favorably in size with the neotype of *M. necatus* from the post-Barstovian-age Fort Randall Formation in the Bijou Hills, South Dakota (Skinner and Taylor, 1967). However, since the antilocaprid material from the northern Cady Mountains is so scarce and fragmentary, no specific assignment can be attempted at this time.

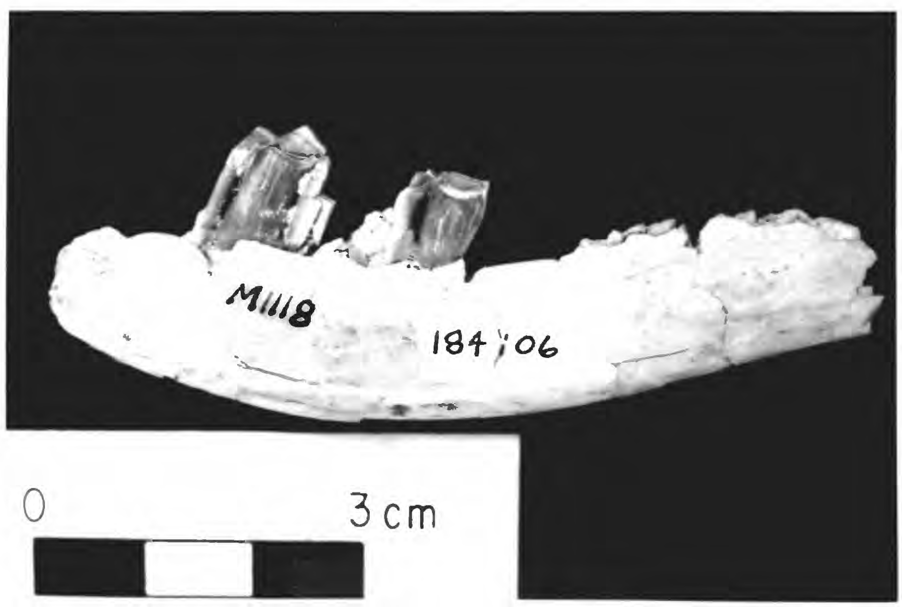

Figure 42.--Merycodus sp., USNM 184106. Right mandible with roots of P/2-4, and fragmentary M/2-3; labial view.

Family CAMELIDAE
AEPYCAMELUS Macdonald, 1956
Cf. Aepycamelus sp.
(Figures 43-46)

Referred specimens: UCR 16905, a partial left mandible with P/4-M/3; 16974, a right mandible fragment with M/2-3; 16385, a partial left mandible with M/1-3; and 16389, a left maxillary fragment with P4/-M2/. All four Riverside specimens are from locality RV-6631. An assortment of large camelid limb elements within the UCR and USNM collections are also tentatively referred to this genus.

Description and comparison with related genera: The specimens conferred to Aepycamelus are much larger than Miolabis, and smaller than Protolabis and Procamelus. The premolars are larger than those of Protolabis. P4/ is single-lobed, with inner and outer cusps separated by a deep fossette (Fig. 43). P4/ shows no lingual median ridge and has a smooth lingual surface. P4/ has no metastyle, and only a weak parastyle in contrast to the P4/ of A. bradyi which has well-developed anterior and posterior styles. The P4/ of cf. Aepycamelus sp. is larger than that of Miolabis.

The upper molars are bilobed with strong parastyles and mesostyles (figs. 43, 44). Deep fossettes separate inner and outer cusps. The specimens from the northern Cady Mountains have weak vertical ribs on M1/, and relatively strong vertical ribs on M2/. M2/ has a stronger mesostyle than does M1/. The metastyle is incipient on M1/, and slightly stronger on M2/. The protocones on M1-2/ are smaller than the hypocones, as in Michenia and Protolabis heterodontus. The lingual borders of the upper cheek teeth are essentially flat and transversely wider than those of Stenomylus.

M/2-3 of Protolabis heterodontus are anteroposteriorly expanded as compared with cf. Aepycamelus sp. There is no metastylid on the lower molars of the northern Cady Mountains specimens (figs. 45, 46), which distinguishes this form from Protolabis. The entoconid of M/3 is larger than that of Miolabis. The anteroposterior diameter of M/3 is within the range of Protolabis heterodontus. Unlike Protolabis, however, the lingual surfaces of the lower molars show now trace of a vertical rib. Measurements of the teeth of cf. Aepycamelus sp. are given in table 6.

Conclusions: The specimens of a large camelid from the northern Cady Mountains are difficult to classify with confidence at the generic level. The specimens are smaller than Protolabis and Procamelus, yet larger than Miolabis. The specimens are larger than the specimens of Michenia from the Arikareean Black Butte Mine local fauna of the southern Cady Mountains (Woodburne, and others, 1974). However, Michenia is a long-ranging species and post-Arikareean specimens of the taxon might be larger than the southern Cady Mountains form. In dental morphology, the northern Cady Mountains form comes closest to Aepycamelus. The specimens are smaller than A. bradyi Macdonald, A. giraffinus (Matthew), A. leptocolon (Matthew), and A. procerus (Matthew and Cook). A. priscus (Matthew) lacks sufficient description for any detailed comparison, but it apparently approaches the Cady Mountains form in size. However, assignment of the Cady Mountains specimens to Aepycamelus must be considered as tentative due to the fragmentary nature of the material and its relative scarcity within the fauna.

Figure 43.--Cf. Aepycamelus sp., UCR 16389. Left maxillary with P4/ to M2/; occlusal view.

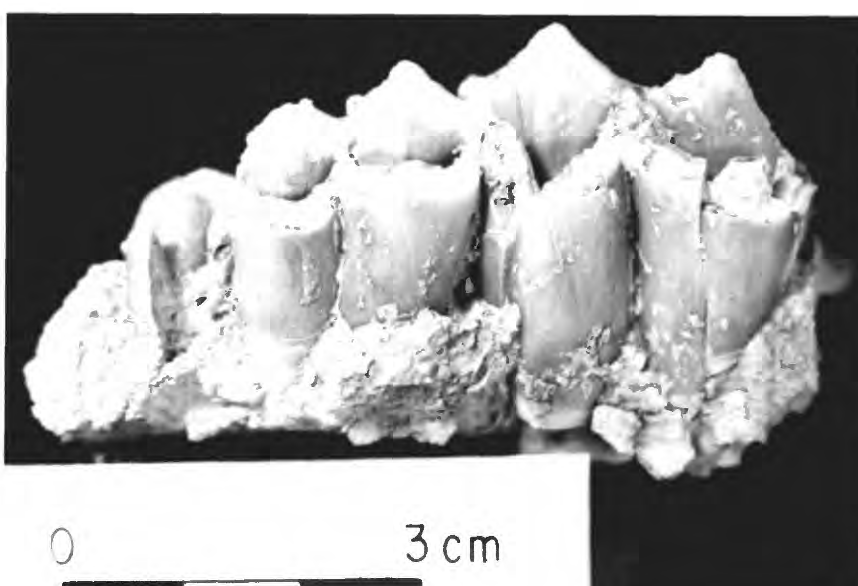

Figure 44.--Cf. Aepycamelus sp., UCR 16389. Left maxillary; lingual view.

Figure 45.--Cf. Aepycamelus sp., UCR 16905. Left mandible with P/4 to M/3, occlusal view.

Figure 46.--Cf. Aepycamelus sp., UCR 16905. Left mandible; labial view.

TABLE 6.--Measurements of Cf. *Aepycamelus* sp. from the Northern Cady Mountains, California (measurements in millimeters; ( ) = approximate measurement)

	UCR 16385	UCR 16974	UCR 16905	UC 16389
P4/ AP				12.65
M1/ AP				(20.60)
Tr				15.70
CH				15.75
M2/ AP				29.60
Tr				20.65
M/2 AP	(22.70)	(29.35)	26.50	
Tr		12.15	(14.15)	
CH	9.35			
M/3 AP	41.25	40.45	(36.80)	
Tr	15.75			
CH	14.90			

"*Miolabis*" *tenuis* Matthew, 1924

Synonomy: *Miolabis tenuis* Matthew, 1924, American Museum of Natural History History Bulletin, v. 50, p. 191, fig. 56.

Type: AMNH 18965, a left mandible and symphysis, from Stonehouse Draw, Horizon A, Sheep Creek beds Sioux County, Nebraska.

Age: The type is from the Sheep Creek local fauna of Hemingfordian age.

Generic and specific characters: *Miolabis* is distinguished by the following dental characters (after Frick and Taylor, 1971): I1-2/ are cupped and larger than those of *Protolabis*; P/1 is lost; the remaining premolars are stouter a and less laterally compressed than in *Protolabis*; the molars are lower crowned and have more distinct metastylids as compared to those of *Protolabis*; M3/3 are less anteroposteriorly expanded than in *Protolabis*. It should be noted that Matthew (1924, p. 191, 193) realized that *Miolabis tenuis* probably did not belong in the genus *Miolabis*. For this reason the generic name is here placed in quotes. Consequently, the generic characteristics apply only in a general sense to "*Miolabis*" *tenuis*.

Matthew (1924, p.191) lists the following characters as typical of species:

"Symphysis shallow, flaring and long sharp-crested diastema between the canine and the cheek teeth; p_1 absent, p_2 vestigial, p_3 and p_4 small and rather short, molars of normal camelid construction, the anteroexternal pillar prominent on m_1 and m_2, the anterointernal pillar prominent on m_2."

"*Miolabis*" cf. "*M.*" *tenuis*
(Figures 47-56)

Referred specimens: USNM 184107, a right maxillary fragment with P4/-M3/; UCR 15981, a left maxillary with P3/-M3/; UCR 16973, a left maxillary fragment with M2-3/; USNM 184108, a left maxillary fragment with P2/, dP3-4/, M1/; UCR 16972, a right maxillary fragment with dP3-4/; UCR 16394, a left maxillary fragment with dP2-4/; USNM 184109, a left mandible with P/4-M/3 and associated metacarpals (fig. 55); UCR 16397, a right mandible with P/3-M/3 and associated left P/2-3; UCR 16391, a right mandible with P/2-M/2; UCR 16398, a left mandible fragment with M/2; UCR 16392, a left mandible with P/4-M/3; UCR 16945, a left mandible with M/2-3; UCR 16947, a left mandible with M/2-3; USNM 184110, a left mandible with dP/2-4, M/1; USNM 184111, a right mandible with dP/2-4, M/1; UCR 16978, left and right mandibles with dP/2-4; UCR 16959, a left mandible with P/2, dP/3-4, and erupting M/1; UCR 16393, a left mandible with dP/2-4, M/1; UCR 16396, a mandible with dP/3-4, M/1; USNM 184112, associated metacarpals III and IV (III is complete, IV is broken at approximately mid-shaft); and UCR 17862, associated complete metatarsals III and IV. All specimens were collected from UCR locality RV-6631 (= USGS locality M1128), except for USNM 184110, which was collected from USGS locality M1131, and USNM 184112, which was collected from USGS locality M1127. Numerous limb elements in the collections of UCR and USNM at the USGS, Menlo Park, are also referred to this species.

Figure 47.--"Miolabis" cf. "M." tenuis, USNM 184107. Right maxillary with P4/ to M3/; occlusal view.

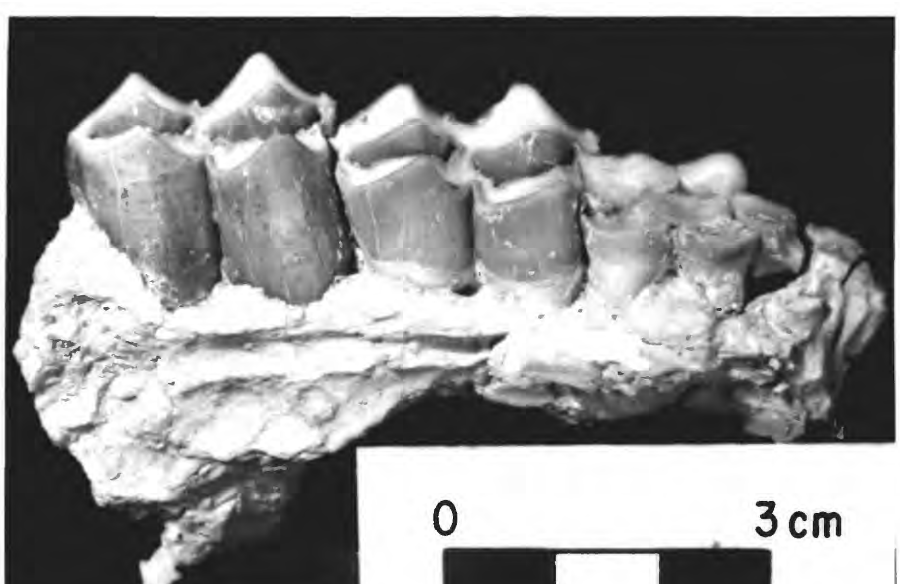

Figure 48.--"Miolabis" cf. "M." tenuis, USNM 184107. Right maxillary; lingual view.

Figure 49.--"Miolabis" cf. "M." tenuis, UCR 16392. Left mandible with P/4 to M/3 and alveolus for P/1; occlusal view.

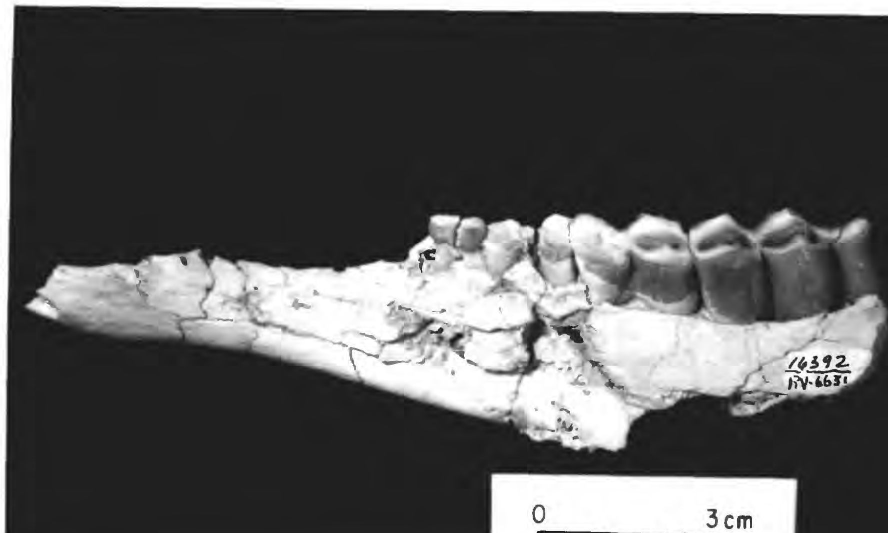

Figure 50.--"Miolabis" cf. "M." tenuis, UCR 16392. Left mandible; labial view.

Figure 51.--"*Miolabis*" cf. "*M.*" *tenuis*, UCR 16391. Right mandible with P/2 to M/2, and alveolus for P/1; occlusal view.

Figure 52.--"*Miolabis*" cf. "*M.*" *tenuis*, UCR 16391. Right mandible; labial view.

Figure 53.--"Miolabis" cf. "M." tenuis, USNM 184109. Left mandible with P/4 to M/3; occlusal view.

Figure 54.--"Miolabis" cf. "M." tenuis, USNM 184109. Left mandible; labial view.

Figure 55.--"Miolabis" cf. "M." tenuis, USNM 184109. Incomplete metacarpus; anterior view.

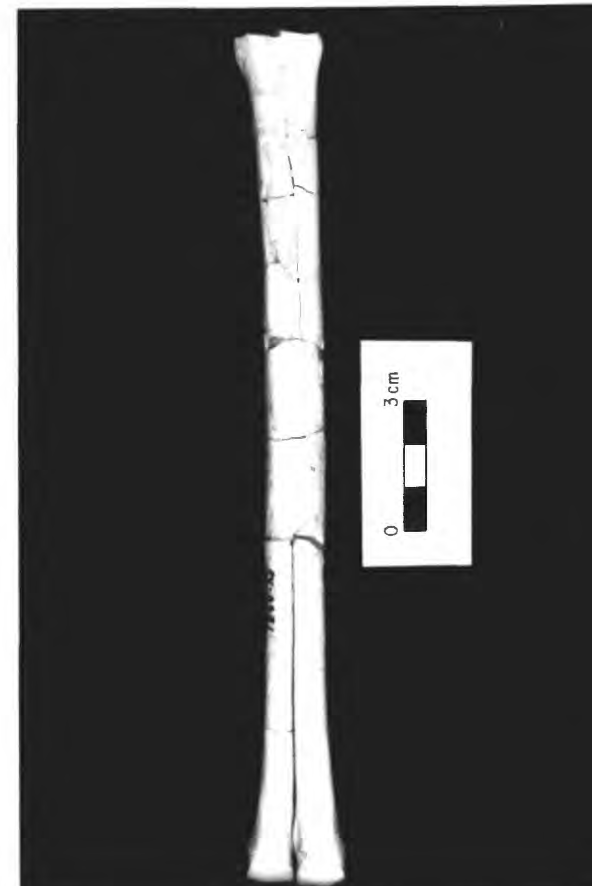

Figure 56.--"Miolabis" cf. "M." tenuis, UCR 17862. Complete metatarsus; anterior view.

Description: Measurements of the referred specimens are given in table 7: P2/ appears to be absent. P3/ has two roots. P4/ has three roots, the largest of which is the internal root. The premolars and molars are all low crowned and small. M1-2/ are nearly square in occlusal outline; M3/ is slightly more rectangular in occlusal outline. M1/ is wider than it is long (table 7). M2-3/ are consistently longer than they are wide. There are no internal or external cingula, and only the faint traces of median ridges. The molars have well-developed parastyles and moderately developed mesostyles, but little or no development of metastyles (figs. 47, 48).

The mandible (figs. 49 through 54) is extremely close in size to that of the type as figured by Matthew (1924, p. 192). It is lightly constructed, and has a shallow, flaring symphysis. The diastema is sharp-crested between the canine and the anterior premolar (either P/2 or P/3). Unlike the type, two of the fourteen available dentaries from the northern Cady Mountains (UCR 16391 and 16392; figs. 49, 52) exhibit alveoli for a two-rooted P/1 on the sharp diastemal crest. Retainment of a P/1 possibly could be considered a primitive feature. A very small P/2 is present in only three specimens one of which retains a P/1. In this specimen, UCR 16391 (figs. 51, 52), P/2 is separated from the alveolus of P/1 by a 24-mm diastema. P/3-4 are small and low-crowned.

As in the type, the lower molars exhibit anteroexternal pillars on M/1-2. The northern Cady Mountains specimens also have a strongly developed anteroexternal pillar on M/3. Anterointernal pillars are present on M/2-3. In the type, M/3 is not fully erupted, so it is impossible to tell whether or not it, too, has a strongly developed anteroexternal or anterointernal pillar. Judging from the figure of the type (Matthew, 1924, p. 192), the teeth of the northern Cady Mountains specimens compare excellently in anteroposterior diameter.

The vertebrate collections from the northern Cady Mountains contain numerous, well-preserved, juvenile specimens of "Miolabis" cf. "M." tenuis. Most of these were collected from the same quarry, and exhibit very little variation in size or in dental morphology. One specimen, however, USNM 184111, is of the same size and exhibits the same general dental morphology as the other juvenile specimens, but has a slightly more robust jaw than do the rest of the specimens. This specimen also has a longer dP/3 as compared to the other juvenile forms. USNM 184111 is the only specimen with these characteristics, and it has been retained within "Miolabis" cf. "M" tenuis because these features could represent variation within the population.

A set of metatarsals, UCR 17862 (fig. 56), fused to just over one half their total length (PD=190 mm), and an unfused, incomplete set of metacarpals (MC IV is broken; PD = 250 mm), also are referred to this species. These metapodials are very slender. The metacarpals are more robust than the metatarsals: The distal width of the metacarpal is estimated at 18 mm (bone has been severely gnawed), as compared with the distal width of the metatarsal, estimated to be 11 mm. The metacarpals and metatarsals are not from the same animal, or even from the same horizon, so these measurements only reflect a very general comparison between the forelimbs and hindlimbs. Some fragmentary metatarsals in the collections from the northern Cady Mountains are more robust than the specimen measured.

TABLE 7.--Measurements of the Teeth of "<u>Miolabis</u>" cf. "<u>M.</u>" <u>tenuis</u> from the Northern Cady Mountains, California (all measurements in millimeters; ( ) = approximate measurement)

		USNM 184107	UCR 15981	UCR 16973	USNM 184109	UCR 16397	UCR 16391	UCR 16398
P3/	AP		10.1					
	Tr		4.95					
	CH		3.9					
P4/	AP	broken	(10.6)					
	Tr	--	--					
	CH	--	--					
M1/	AP	13.55	12.35					
	Tr*	(15.4)	(15.6)					
	CH	3.5	--					
M2/	AP	23.6	21.8	--				
	Tr	(18.0)	17.4	20.5				
	CH	12.7	8.6	10.3				
M3/	AP	23.7	(24.6)	--				
	Tr	19.5	(17.7)	20.8				
	CH	18.9	--	--				
P/2	AP						5.4	
	Tr"						2.95	
	CH"						4.1	
P/3	AP					7.1	7.15	
	Tr"					3.45	3.35	
	CH"					3.6	4.9	
P/4	AP				9.5	10.6	(12.1)	
	Tr"				4.75	broken	4.5	
	CH"				5.7	5.8	8.2	
M/1	AP				broken	10.4	13.7	
	Tr				--	6.9	8.1	
	CH				--	broken	5.7	
M/2	AP				20.15	20.4	22.3	20.95
	Tr				10.75	11.7	9.45	10.05
	CH				9.6	13.3		8.9
M/3	AP				(30.6)	30.4		
	Tr				(13.3)	14.0		
	CH				--			
P2/-M3/			(78.1)					
P/2-M/2					(52.6)		(62.75)	
Mandible depth below M/1						27.1	(24.75)	30.4
Alveolus for P/1							6.6	

* across protoloph

" maximum

Table 7.--Continued

	UCR 16947	UCR 16945	UCR 16392	USNM 184108	UCR 16972	UCR 16394	USNM 184110
P/4 AP			(9.4)				
Tr"			5.05				
CH"			3.6				
M/1 AP			broken				broken
Tr			--				--
CH			--				--
M/2 AP	16.75	18.5	18.95				
Tr	9.05	9.9	12.0				
CH	(6.8)	8.1	8.45				
M/3 AP	27.3	30.1	31.1				
Tr	10.5	13.0	13.8				
CH	9.9	10.9	(16.8)				
dP2/ AP						9.55	
Tr						2.85	
CH						4.25	
P2/ AP				8.9			
Tr				4.25			
CH				3.85			
dP3/ AP				8.5	14.55	16.7	
Tr				(5.0)	5.15	5.7	
CH				--	(6.2)	9.35	
dP4/ AP				13.45	(18.45)	18.1	
Tr				(10.05)	11.3	10.35	
CH				5.4	(11.7)	(11.35)	
M1/ AP				8.05			
Tr				12.55			
CH				--			
dP/2 AP							broken
Tr							--
CH							--
dP/3 AP							(10.75)
Tr							(3.4)
CH							4.65
dP/4 AP							22.15
Tr							6.4
CH							(12.15)
P/2-M/2			(51.5)				
Mandible depth below M/1			(29.5)				
Alveolus for P/1			6.6				
dP/2-4							42.55
Mandible depth below dP/3							13.05

" maximum

TABLE 7.--Continued

	USNM 184111	UCR 16396	UCR 16959	UCR 16393	UCR 16978 Left	UCR 16978 Right
dP/2 AP	10.05			9.05	8.9	9.0
Tr	(3.3)			2.55	2.6	2.8
CH	5.2			3.8	4.15	4.0
P/2 AP			5.95			
Tr"			2.3			
CH"			(3.3)			
dP/3 AP	12.7	8.3	broken	10.5	9.95	10.65
Tr	3.7	3.0	--	3.3	3.7	3.65
CH	5.7	2.2	--	4.6	5.45	5.85
dP/4 AP	20.4	(17.95)	broken	21.55	22.6	20.75
Tr	8.0	6.25	--	6.65	6.5	(6.8)
CH	11.4	3.4	--	(11.05)	(9.9)	--
M/1 AP	unerupted	16.9		22.2		
Tr		7.85				
CH		12.85				
M/2 AP		22.7				
Tr		(30.2)				
CH		20.1				
dP/2-4	41.2			40.3	41.35	40.3
P/2-dP/3-4			(32.9)			
mand. depth below dP/3	14.3		(14.0)		12.85	12.7

" maximum

Comparison with related species: The other species of *Miolabis* are significantly larger and more heavily constructed than is "*Miolabis*" cf. "*M. tenuis*, and all have lost P/1. *Oxydactylus* may be distinguished from "*M. tenuis* by its larger size, deeper ramus, and lack of an anteroexternal pillar on M/3. *Michenia agatensis* has a lower molar series of approximately the same size as the Cady Mountains specimens (Frick and Taylor, 1971). However, specimens of *Michenia* in the UCMP have teeth that are more laterally compressed than those of the Cady Mountains form, especially P/3 and the lower molar series. All species of *Aepycamelus*, *Protolabis* and *Procamelus* are much larger than "*Miolabis*" *tenuis*. In addition, the metacarpal is shorter than the metatarsal in *Protolabis*, while the reverse seems to be true in the Cady Mountains form.

Conclusions: The small camelids of the northern Cady Mountains compare excellently both in size and in dental morphology with "*Miolabis*" *tenuis* from the Sheep Creek beds of Nebraska. The referral is left tentative at this time, however, because the author has not studied the type and referred material in the AMNH collection.

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