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AN ASSESSMENT OF THE VERTEBRATE PALEOECOLOGY AND BIOSTRATIGRAPHY OF THE SESPE FORMATION, SOUTHERN CALIFORNIA

by
Thomas M. Bown[1]

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[1] USGS, Denver, Colorado

Abstract

Fossil vertebrates occurring in the continental Sespe Formation of southern California indicate that deposition of the upper third of the lower member and the middle and upper members of the formation took place between Uintan (middle Eocene) and late early or early late Arikareean (latest Oligocene or earliest Miocene) time. Chadronian (latest Eocene) mammalian faunas are unknown and indicate a period of intraformational erosion also substantiated by sedimentologic data. The Sespe environment was probably savannah with gallery forest that formed under a climate with wet and dry seasons. More detailed knowledge of Sespe sediment accumulation rates and paleoclimates can be obtained through paleosol and alluvial architecture studies.

Introduction

The continental Sespe Formation (Watts, 1897) consists of over 1,650 m of coarse to fine lithic sandstone, pebble to cobble conglomerate, and variegated mudrock and claystone that is best exposed in the Simi Valley area of the Ventura Basin, southern California. It is unconformably underlain by the largely marine Llajas Formation (lower to middle Eocene; Squires, 1981), and is variously overlain conformably (gradationally) by the Vaqueros Formation (?upper Oligocene to lower Miocene; Blake, 1983), or unconformably by the Calabasas or Modelo Formations (middle Miocene), or the Pliocene Saugus Formation (Taylor, 1983). The Llajas, Calabasas, Modelo, and Saugus Formations are of marine origin, whereas the base of the Vaqueros Formation records a transition between continental and marine conditions (Reid, 1978; Blundell, 1983; Lander, 1983).

Traditionally, the Sespe is divided into three unnamed members (Kew, 1919, 1924; Heatherington, 1957; Pasta, 1958; Van Camp, 1959) that vary considerably in thickness laterally. The lower member and the lower two-thirds of the upper member consist principally of lithic arkosic sandstone with minor amounts of gravel and cobble conglomerate and mudrock (Taylor, 1983). The middle member is made up of coarse, micaceous arkose (about 60%) and variegated, mottled "claystone." The upper third of the upper member contains micaceous, medium to coarse lithic arkose (about 50%), fine calcareous sandstone (25%), and mottled "claystone." Taylor (1983) recognized the following Sespe depositional environments based on grain size and primary bedding structures: 1) sandy, braided river, 2) meandering river, 3) floodplain overbank, and 4) salt marsh and coastal environments. He further suggested that the transition from braided river alluvial deposition (in the lower member and lower two-thirds of the middle member) to meandering river alluvial and coastal floodplain deposition (in the upper part of the formation) might record periods of uplift and subsidence, respectively.

Fossil vertebrates of the Sespe Formation, especially those of mammals, have been known for more than 60 years (Stock, 1930), and shark, ray, bony fish, and desmostylid and cetacean mammal remains have been found in the overlying Vaqueros Formation (Squires and Fritsche, 1978). Fossil vertebrates occur abundantly in all three members of the Sespe Formation, and recent collecting, especially in the middle member (Kelly and others, 1991), has substantially augmented older records. Today, Sespe fossil mammals comprise over 100 species, grouped in 35 families and 12 orders (Table 1). In conjunction with the slightly older mammal faunas (Novacek, 1976; Novacek and Lillegraven, 1979) of the Friars and Mission Valley Formations farther south (Poway Group; Kennedy and Moore, 1971), Sespe mammals are among the most important known from the later Eocene of North America (Wood and others, 1941; Krishtalka and others, 1987; Mason, 1983; Savage and Russell, 1983; Kelly and others, 1991). Previously viewed to be late Eocene through early Miocene in age, refined vertebrate correlations and recalibrations of the Tertiary time scale in recent years indicate that the Sespe Formation accumulated from sometime in the late middle Eocene until the latest Oligocene or earliest Miocene.

Knowledge of the age and paleoenvironment of the Sespe Formation and units within it are important for: 1) dating episodes of local tectonism; 2) providing correlation with marine rocks (although Sespe rocks outcrop near the Pacific coast, there is no direct continental to marine correlation that involves Sespe rocks--Krishtalka and others, 1987); 3) providing information on the record of continental climatic change during the middle and later Eocene; and 4) ascertaining the nature and rapidity of climatic deterioration at the Eocene-Oligocene boundary. The purpose of this report is to: 1) briefly document for the U.S. Geological Survey Southern California Areal Mapping Project the current knowledge of age correlations and paleoenvironments of the Sespe Formation based on what is known of its vertebrate faunas and sedimentology; and 2) offer supplemental comments on how available and ungathered data might be used to strengthen correlations between the continental Sespe Formation and marine formations of our southern Pacific coast.

Age of Sespe Formation

Vertebrates have traditionally been deemed too rare and their occurrences too spotty to be of much use in the detailed age correlation of continental sequences, a misconception that has been perpetuated by the non-biostratigraphic approaches of many (if not most) vertebrate paleontologists in the last 150 years (see, for example, discussion in Bown and others, 1994). Although the lamentable condition of vertebrate biostratigraphy has been substantially redressed in recent years, many important local biostratigraphies are still not tied to local sections, and relatively few local sections with good vertebrate records are well correlated with marine records (or with each other, for that matter) by geochronologic investigations. The standard approach has been to identify the fossil vertebrates collected and to group them into "local faunas" that commonly include vertebrates occurring through many tens to hundreds of meters of section. The "local faunas" are then correlated with "land mammal ages," units that are provincial to continental in scope and generally incorporate time spans of many million years. With two or three notable exceptions, vertebrate biostratigraphies even approaching the fine detail available for macro- and microinvertebrates of the marine realm simply do not exist.

Coupled with correlation problems inherent in working with a rather coarse vertebrate biostratigraphic framework is the viewpoint of many workers (myself included) that very few fossil vertebrate species can be correlated over wide areas. This fact obtains especially for mammals of the early Tertiary of western North America because of the evolution of endemic species during Paleocene-Eocene orogenic development of intermontane basins. Rising mountain barriers not only facilitated the allopatric evolution of new endemic species from more widespread stocks, they also served to inhibit later interchange between separated species. The mammalian faunas of the Sespe Formation are cases in point and contain many species (and even genera) that evidently arose from more widespread early Tertiary forebears, but which were apparently endemic to (southern?) California and are unknown in the generally better sampled early-middle Tertiary mammalian faunas of the Rocky Mountain and Great Plains regions (Black and Dawson, 1966; Lillegraven, 1977; Novacek and Lillegraven, 1979). This endemism appears to have been more marked for the Sespe Formation/Santiago Formation mammal assemblages than for the slightly older Friars Formation/Mission Valley Formation mammals from farther south in near-coastal California (Golz and Lillegraven, 1977).

As a result of collecting efforts over the past decade, the vertebrate fauna of the Sespe Formation has become much better known, especially as two recent publications have tabulated sectioned-controlled vertebrate occurrences for all three Sespe members (Lander, 1983; Kelly and others, 1991). As of this writing, more than 65 Sespe fossil vertebrate localities are known; two are from the lower member, at least 38 from the middle member, and at least 25 from the upper member. The mammalian faunas known from each member are depicted in Table 1.

Until about twenty years ago, most of the classic vertebrate "land mammal ages" were believed to record a particular episode of time, corresponding to "early, middle, and late" parts of the Tertiary epochs. Under this scheme, the Bridgerian corresponded to the middle Eocene, the Uintan to the late Eocene, and the Duchesnean to the latest Eocene. The Oligocene land mammal ages are the Chadronian (earliest Oligocene), Orellan, and Whitneyan, whereas the Arikareean is the first mammal "age" of the Miocene (Wood and others, 1941). Geochronologic correlations between well-sampled localities containing fossil mammals characteristic of the early Tertiary land-mammal ages (for example, Obradovich and others, 1973; Mauger, 1977; Berggren and others, 1985; Prothero, 1984, 1985a, 1985b, 1988, 1990; Prothero and others, 1982a, 1982b; Prothero and Swisher, 1990; Swisher and Prothero, 1990; Lucas, 1992) and paleomagnetic records from Eocene and Oligocene type sections in Europe have led to considerable recent revision of the temporal positions of the North American land mammal ages. For example, Aubrey and others (1988) showed that the Bartonian-Priabonian (middle-late Eocene) boundary lies in the upper part of Chron 17R. Early Duchesnean faunas therefore are late middle Eocene in age, whereas late Duchesnean faunas belong to the early late Eocene (Holroyd and Maas, in press). Because Chron 20R includes the boundary between the Bridgerian and Uintan land mammal ages (Prothero and Swisher, 1992), the majority of Uintan time (hitherto late Eocene) actually belongs to the middle Eocene. Moreover, concensus recalibration of the Eocene-Oligocene boundary to about 34 million years (in Chron 13R--see discussion in Berggren and others, 1992) demonstrates that probably all of the Chadronian land mammal age is late Eocene as well (Prothero and Swisher, 1992; Stucky, 1992).

Based on the co-occurrences of the marsupial *Peratherium*, the dormaaliid insectivore *Sespedectes singularis*, and the zapodid rodent *Simimys*, Kelly and others (1991) believed that the upper part of the lower member of the Sespe Formation (the only part of the lower member containing fossil vertebrates) is of Uintan age (middle Eocene).

The Simi Valley Landfill local fauna from the upper part of the middle member of the Sespe Formation is middle to late Duchesnean (late middle Eocene to early late Eocene--probably including Chron 17R) based on the joint occurrences of the rodents *Namatomys, Paradjidaumo,* and *Simimys,* and the hypertragulid artiodactyl *Simimeryx.* Mammals from the top of the upper Member of the Sespe Formation (some possibly from the base of the conformably overlying Vaqueros Formation) include the lagomorph *Archaeolagus,* the rodent *Leidymys nematodon,* and the hypertragulid artiodactyl *Hypertragulus hesperius.* This is clearly the youngest Sespe vertebrate fauna and it was assigned a late early to early late Arikareean (latest Oligocene or earliest Miocene) age by Lander (1983). This uppermost Sespe fauna overlies several well sampled faunas in the upper member, including the Kew Quarry local fauna (late Orellan to early Whitneyan = early to middle Oligocene), and the less well known Shells Canyon, Grimes Canyon, East Fork of Maria Ygnacio Creek, Sycamore Canyon, and Cañada de la Gaviota local faunas--all of late early Arikareean (latest Oligocene) age.

Based on fossil mammal faunas, that part of the Sespe Formation above the base of the upper third of the lower member ranges in age from middle Eocene to latest Oligocene or earliest Miocene. The lower two-thirds of the lower member of the Sespe lacks mammals and there is no record of Chadronian (middle late and latest Eocene) faunas. Howard (1987) records an interval of missing section in the Sespe Formation, corresponding to late Chadronian and all of Orellan time. With the description of Orellan faunas from the Sespe (Kelly and others, 1991) and the reapportionment of middle Eocene to early Oligocene geochronology discussed above, it appears that Howard's Sespe intraformational unconformity is confined to upper Chadronian (latest Eocene) time.

Temporal relations of Sespe rocks and vertebrate faunas to North American land mammal ages and important geochronologic markers are illustrated in Figure 1.

Paleoenvironment of Sespe Formation

The Sespe Formation is a remnant of a great clastic wedge of continental sediment, thickest on the east, that records a prolonged major westward marine regression from southern California. Taylor (1983, p. 129) believed that two cycles of regional uplift and subsidence are represented by "***the change in stream-gradient characteristics of the three [Sespe] facies." The three facies are: 1) the lower member and the lower two thirds of the upper member, which Taylor believed to be sandy braided river deposits; 2) the middle member, believed to be meandering river floodbasin deposits; and 3) the upper third of the upper member, thought to represent coastal floodplain sediments. Taylor (1983) thought the braided river deposits formed during uplift cycles, whereas the meandering river floodplain and coastal deposits accumulated during periods of subsidence.

The alluvial architecture of the Sespe Formation (90% sandstone and conglomerate in facies 1, and 60% sandstone and 40% mudstone in facies 2) suggests a somewhat different interpretation. Bridge and Leeder (1979) and Alexander and Leeder (1987) found that more-or-less stable tectonic conditions result in alluvial sand packages with a relatively high degree of interconnectedness (high percentage of sandstone and low percentage of mudrock). Conversely, subsidence produces sand packages with less connectedness (that is, more mudrock) due to more rapid shifting of stream channels. Under this scenario, Sespe depositional history was: 1) accumulation under relatively stable tectonic conditions (upper two-thirds of lower member--little uplift or subsidence); 2) accumulation controlled by increased subsidence (middle member); 3) erosion (top of middle member=latest Eocene); 4) accumulation under relatively stable tectonic conditions (lower two-thirds of upper member); and 5) accumulation controlled by increased subsidence, leading ultimately to marine transgression (upper third of upper member of Sespe Formation and conformably overlying Vaqueros Formation).

Paleosols occur throughout the Sespe Formation and offer the best promise for more more detailed control on **continuous** sediment accumulation rates during Sespe time (for example, Leeder, 1975; Bown and Kraus, 1993; Kraus and Bown, 1986, 1993).

Sespe deposits record the Eocene-Oligocene transition, and the attendant change in the composition of mammalian faunas throughout western North America was almost equally as profound as that at the Paleocene-Eocene boundary. Archaic orders of mammals predominated until the late Eocene when they were replaced by mammals of more modern aspect. Among major groups that went extinct were the Order Multituberculata (Subclass Allotheria), Suborder Pantolesta, Family Miacidae (Order Carnivora), Order Creodonta, and Order Plesiadapiformes. Seventy-one families of mammals appear in the late Eocene or early Oligocene (Black and Dawson, 1966; Lillegraven, 1972), and of 127 recognized Chadronian mammal genera only 31 are known from Duchesnean and older faunas (Savage and Russell, 1983).

Early Tertiary mammals are generally poor indicators of paleoclimatic change unless the faunas are very diverse, are well-sampled, and the record is stratigraphically dense. This is true because most of the pre-Oligocene mammals were members of archaic groups with no living descendents. However, body size, one of the most fundamental adaptations in mammals, has recently been shown to be related to mean annual temperature change through time (Bown and others, in press). Exceptionally dense fossil records (greater than those currently known from the Sespe Formation) are necessary to explore this paleoclimatic indicator.

Some general considerations regarding Eocene-Oligocene climatic change have been gleaned from the excellent records of these mammals in the western interior of North America. These interpretations are broadly applicable to Sespe paleoenvironments insofar as the southern Californian and western interior faunas share taxa or contain closely related taxa. For example, the decline of diversity of Perissodactyla and the rise of diversity in Artiodactyla over the Eocene-Oligocene boundary records the extinction of many browsing forest forms (principally tapirs) and the advent of generally larger mammals adapted for running in relatively open country. Savage and Russell (1983) suggested that fossil vertebrates show Uintan environments to have been characterized by savannahs with forested stream valleys, noting, however, that the diversity of arboreal micromammals testifies to at least some extensive woodlands. By the end of the Duchesnean, the component of arboreal mammals present in early and middle Eocene faunas had dropped by about 95 per cent.

Mechanical analyses of Sespe sediments and studies of Sespe mineralogy led Reinhardt (1928) and Gianella (1928) to conclude that the Sespe Formation was deposited under warm, semiarid conditions. Study of paleosols led Peterson and Abbott (1979) to a similar conclusion regarding the environment of deposition of the Uintan Friars and Mission Valley Formations of southwestern California and northern Baja California. Using clay mineral proportions and the depths to calcareous nodular horizons in late Eocene through late Oligocene paleosols developed in Badlands National Park, Retallack (1992) concluded that mean annual precipitation there was on the order of 1,000 mm during the Duchesnean, 450-500 mm in the Whitneyan, and that it had declined to about 350-450 mm by the Arikareean.

The four above studies seem to suggest that climatic drying during the Eocene-Oligocene transition might have occurred earlier on the Pacific coast than in the central United States. Novacek and Lillegraven

(1979) utilized the fossil vertebrate composition of the Mission Valley and Friars Formations to challenge the semiarid paleoclimates inferred for the Californian Uintan by Peterson and Abbott (1979). According to Novacek and Lillegraven (1979, p. 77), ephemeral river and stream systems would be inadequate to support the abundance and diversity of semiaquatic amphibians, crocodilians, soft-shelled turtles, and "***presumably scansorial to arboreal marsupials, insectivores, and primates***" found in the Uintan deposits. This reasoning applies equally well to faunas of similar composition from the Sespe Formation, especially those of the lower and middle members. Novacek and Lillegraven went on to suggest that Friars and Mission Valley paleoenvironments were more complex than envisioned by Peterson and Abbott (1979) and was perhaps similar to that in parts of East Africa "***where riparian habitats grade into gallery forests and/or savannah within a few kilometers." This assessment is logical and, curiously, is remarkably consistent with the much earlier conclusions of Reed (1929) that the degree of pre-lithification weathering of Sespe sediments indicates warmth and humidity, possibly in a climate having wet and dry seasons.

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TABLE 1. Fossil Mammals of the Sespe Formation (Original taxonomic assignments and revisions drawn from Coombs, 1971; Gazin, 1958; Golz, 1976; Golz and Lillegraven, 1977; Kelly, 1990; Kelly and others, 1991; Kelly and Whistler, 1994; Lander, 1983; Lillegraven, 1972, 1976, 1979, 1980; Lillegraven and others, 1981; Lillegraven and Wilson, 1975; Lindsay, 1968; Mason, 1988a, 1988b, 1990; McKenna, 1959; Raschke, 1984; Stock, 1930, 1931, 1933a, 1933b, 1934a, 1934b, 1934c, 1934d, 1935a, 1935b, 1935c, 1935d, 1936a, 1936b, 1938, 1939, 1948; Tedford, 1961; Wilson, 1935, 1940a, 1940b; Wood, 1956, 1962).

Upper Member of Sespe Formation

- Order Artiodactyla
  - Family Merycoidodontidae
    - **Sespia nitida**
    - **Merycoides pariogonus**
    - **Oreodontoides oregonensis**
    - **Leptauchenia**? (**Sespia**) **californica**
    - **Mesoreodon major**
  - Family Hypertragulidae
    - **Hypertragulus hesperius**
    - **Hypertragulus calcaratus**
  - Family Anthracotheriidae
    - **Elomeryx armatus**
  - Family Camelidae
    - **Stenomylus** ? **campester**
    - **Dyseotylopus migrans**
- Order Perissodactyla
  - Family Equidae
    - **Miohippus annectens**
  - Family Rhinocerotidae
    - **Subhyracodon occidentalis**
    - **Subhyracodon annectens**
    - **Subhyracodon gregoryii**
    - **Diceratherium pacificum**
- Order Rodentia
  - Family Ischyromyidae
    - **Sespemys thurstoni**
  - Family Geomyidae
    - **Entoptychus basilaris**
  - Family Cricetidae

        - **Leidymys nematodon**
        - **Paciculus** sp.
        - **Proheteromys**? **bodei**
- Order Lagomorpha
    - Family Leporidae
        - **Archaeolagus**? sp.
        - **Palaeolagus** sp.
- Order Carnivora
    - Family Canidae
        - **Enhydrocyon stenocephalus**
        - **Temnocyon altigenis**
        - **Mesocyon coryphaeus**
        - **Nothocyon**? **pavidus**
    - Family Felidae
        - **Nimravus brachyops**
        - **Eusmilus cerebralis**

Middle Member of Sespe Formation

- Order Polyprotodonta
    - Family Didelphidae
        - **Peratherium** sp., cf. **P. knighti**
        - **Nanodelphys californicus**
- Order Lipotyphla
    - Family Dormaaliidae
        - **Sespedectes davisi**
        - **Sespedectes singularis**
        - **Proterixoides davisi**
    - Family Geolabididae
        - **Batodonoides powayensis**
        - **Centetodon** sp., cf. **C. aztecus**
- Order Cimolesta
    - Family Pantolestidae
        - **Simidectes merriami**
- Order Apatotheria
    - Family Apatemyidae
        - **Apatemys bellus**
- Order Creodonta
    - Family Hyaenodontidae
        - **Hyaenodon vetus**
        - **Hyaenodon venturae**

Hyaenodon exiguus
Pterodon californicus
Order Plesiadapiformes
Family Microsyopidae
Craseops sylvestris
Uintasorex sp., cf. **U. montezumicus**
Order Euprimates
Family Omomyidae
Macrotarsius roederi
Dyseolemur pacificus
Chumashius balchi
Yaquius travisi
cf. **Hemiacodon** sp.
omomyidae, indeterminate
Order Artiodactyla
Family Dichobunidae
Tapochoerus egressus
dichobunidae, indeterminate
Family Merycoidodontidae
Leptoreodon edwardsi
Leptoreodon stocki
Leptoreodon sp., cf. **L. leptolophus**
Family Agriochoeridae
Protoreodon annectens
Protoreodon pacificus
Protoreodon pumilus
Family Hypertragulidae
Simimeryx hudsoni
Simimeryx sp.
Family Oromerycidae
Protylopus robustus
Protylopus sp., cf. **P. petersoni**
Protylopus pearsonensis
Protylopus stocki
Eotylopus sp.
Family Camelidae
Poebrodon sp.
Protylopus pearsonensis
indeterminate camelid (of Kelly and Whistler, 1994)
Family Protoceratidae
protoceratid, indeterminate

- Order Perissodactyla
  - Family Isectolophidae
    - isectolophidae, indeterminate (of Kelly and Whistler, 1994)
  - Family Helaletidae
    - **Dilophodon** sp.
  - Family Brontotheriidae
    - **Duchesneodus californicus**
    - **Protitanops curryi**
    - **Teleodus** sp.
  - Family Amynodontidae
    - **Amynodontopsis bodei**
    - **Amynodon** sp., cf. **A. advenus**
  - Family Hyracodontidae
    - **Triplopus? mortivallis**
    - triplopine hyracodontid?
- Order Rodentia
  - Family Ischyromyidae
    - **Microparamys tricus**
    - **Microparamys** sp.
    - **Microparamys woodi**
    - **Leptotomus caryophilus**
    - **Leptotomus leptodus**
    - **Leptotomus tapensis**
    - **Leptotomus** sp. indet. (of Kelly and Whistler, 1994)
    - **Ischyrotomus** sp., cf. **I. compressidens**
    - **Mytonomys burkei**
    - **Rapamys fricki**
  - Family Aplodontidae
    - **Eohaplomys serus**
    - **Eohaplomys matutinus**
    - **Eohaplomys tradux**
  - Family Eomyidae
    - **Paradjidaumo** sp.
    - **"Namatomys"** sp., cf. **"N." fantasma**
    - **"Namatomys"** sp.
  - Family Geomyidae?
    - **Gryphomys alecer**
  - Family Zapodidae
    - **Simimys simplex**
    - **Simimys** sp.
  - Family Cylindrodontidae

        - **Pareumys** sp., cf. **P. milleri**
        - **Pareumys** sp.
        - **Presbymys lophatus**
        - cylindrodontid, indeterminate
    - Family Heteromyidae
        - **Heliscomys** sp. nov.
- Order Carnivora
    - Family Miacidae
        - **Tapocyon occidentalis**
        - **Procynodictis progressus**
        - Miacis sp. (of Kelly and Whistler, 1994)
        - Miacis? **hookwayi**

Lower Member of Sespe Formation

- Order Polyprotodonta
    - Family Didelphidae
        - **Peratherium (?Herpetotherium)** sp.
- Order Lipotyphla
    - Family Dormaaliidae
        - **Sespedectes singularis**
- Order Rodentia
    - Family ?Zapodidae
        - **Simimys** sp.

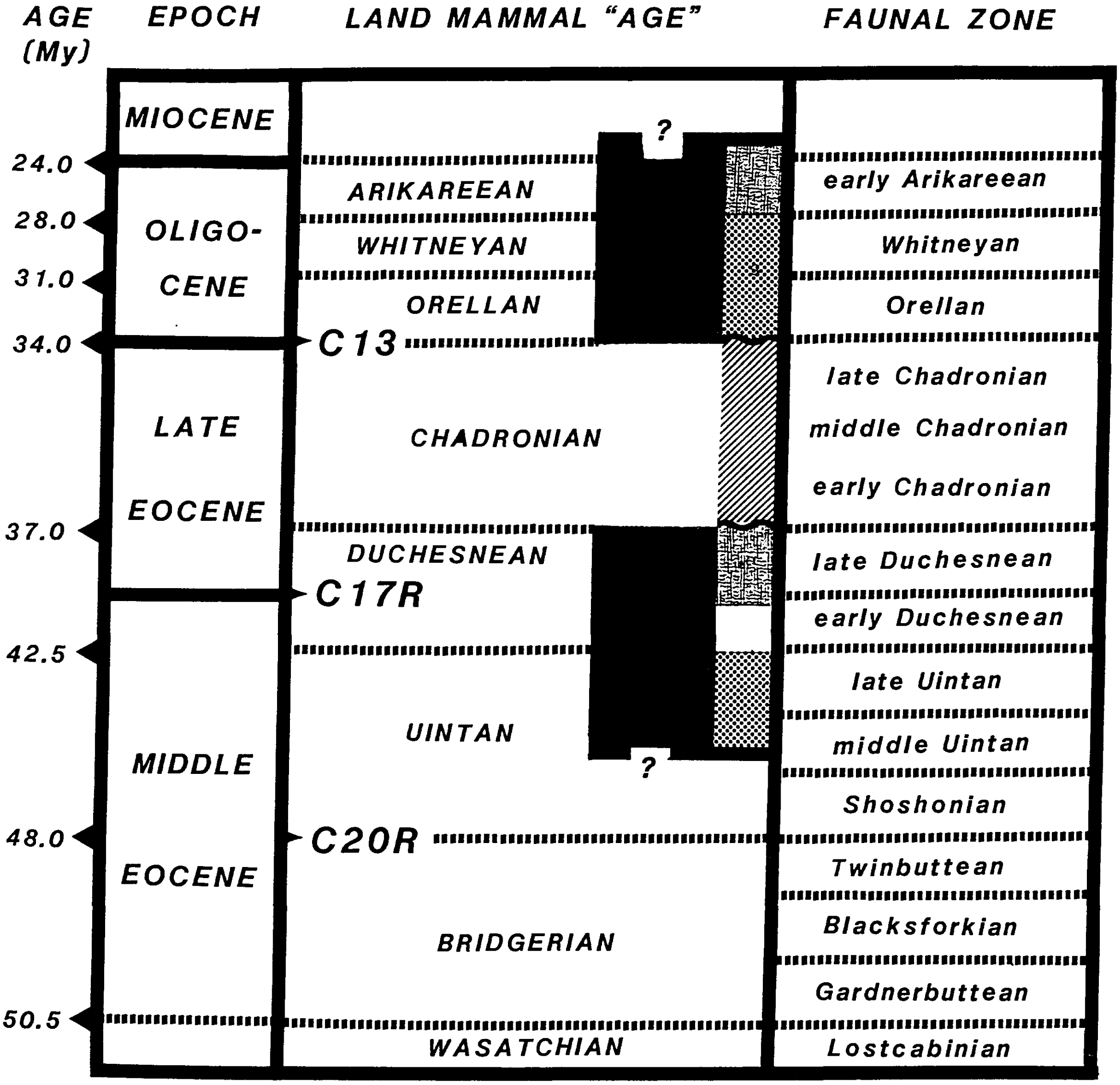

Figure 1. Diagram depicting age range of Sespe Formation (black) and episodes of erosion and different depositional style, with respect to North American land mammal "ages" and "subages," and paleomagnetic chronology. Oblique lines = erosion; dotted = little to moderate subsidence; pattern = moderate to great subsidence; blank = unknown. Patterned after Stucky (1992), but with addition of data.