New Evidence for the Age of the South Mountain Local Fauna, Ventura County, California

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ABSTRACT. The South Mountain Local Fauna is a small assemblage of fossil vertebrates from the uppermost beds of the Sespe Formation in Ventura County, California, U.S.A. The remains of mammals have been found in a variegated interval of sandstones and mudstones. Vertebrate fossils have been collected from within an interval of about 638 m (2100 ft.). Included in this local fauna is the oreodont *Sespia californica* (Stock, 1930), which has affinities with *S. marianae* Schultz and Falkenbach, 1948, from the lowest part of the Arikaree Group of Nebraska.

A ^{40}K-^{40}Ar age of 28.2 ± 0.2 Ma (weighted average of two analyses) was obtained on biotite from the Willard Canyon tuff, a pumiceous bed that lies about 271 m stratigraphically below the top of the Sespe Formation at South Mountain. Because previous work in Nebraska has yielded similar isotopic ages, both of the mentioned species of *Sespia* are now closely tied to dates of about 28 Ma. These data support the faunal correlation and land mammal age assignment of Arikareean for the South Mountain Local Fauna. The age determination for the Willard Canyon tuff reaffirms an approximate 28 to 29 Ma age for the earliest Arikareean.

The South Mountain Local Fauna is overlain by a "Vaqueros" Stage molluscan assemblage from the Vaqueros Formation. The Zemorrian–Saucesian Pacific Coast benthic foraminiferal stage boundary is approximately coincident and has been dated at 22 to 23 Ma, thus providing a minimum age for the Sespe–Vaqueros contact at South Mountain.

A specimen referable to *Sespia* has been collected from South Mountain at a stratigraphically higher level than previously reported material of this taxon.

The Alamos Canyon Local Fauna near Big Mountain is not younger than early Arikareean due to the constraints imposed by overlying "Vaqueros" Stage mollusks and early Saucesian (late Zemorrian?) foraminifera.

INTRODUCTION

The Sespe Formation is a thick, predominantly nonmarine, clastic unit that is widely exposed in the northern Peninsular and southern Transverse Ranges of southern California (Fig. 1). At South Mountain, south of Santa Paula in Ventura County, approximately 638 m (2100 ft.) of the upper part of the Sespe Formation are exposed along the north flank of the South Mountain–Oak Ridge anticline. The total stratigraphic thickness of the Sespe in the vicinity of South Mountain is about 1800 to 2100 m (6000 to 7000 ft.) as determined from well-core data obtained from oil wells in the South Mountain Field (Stock, 1930; Baddley, 1954). The lithology is characterized by alternating variegated sandstones and red mudstones. A single tuffaceous mudstone also lies within the upper part of the South Mountain section. The Sespe Formation at South Mountain is unconformably overlain by the marine Vaqueros Formation as it is elsewhere in the Ventura Basin (Stock, 1930; Yeats, 1987).

Fossil vertebrates that have been collected from the Sespe Formation within the Ventura Basin suggest a range of North American Land Mammal Age (NALMA) assignments of Uintan to Arikareean (Stock, 1948). The steep badland exposures of the Sespe Formation at South Mountain have produced a small fossil vertebrate sample from the uppermost beds (Figs. 1 and 2). Among the taxa reported from this area is the holotype of *Sespia californica* (Stock, 1930), which is noteworthy for being one of the taxa that characterize the early Arikareean NALMA. Stock (1930, 1934) and Wilson (1949) are the primary authorities for description of the South Mountain Local Fauna. Previous discussions of the systematic and temporal implications for the South Mountain Local Fauna have been presented by Schultz and Falkenbach (1949, 1954, 1968), Durham *et al.* (1954), Stirton (1960), and Savage and Russell (1983). Stirton (1960) has provided the most recent faunal list and suggested marine correlations.

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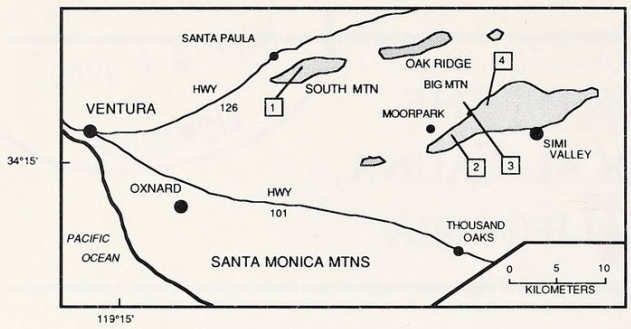

Figure 1. Index map of the southern portion of Ventura County, California, with fossil localities and major outcrops of the Sespe Formation indicated. Dot pattern represents major Sespe outcrops. Locality numbers are as follows: 1) South Mountain Local Fauna; 2) "Moorpark leptauchenid"; 3) Big Mountain marine invertebrate localities; 4) Alamos Canyon Local Fauna.

MATERIALS AND METHODS

^{40}K-^{40}Ar ANALYSES

A sample of the Willard Canyon tuff was collected for analysis at the Berkeley Geochronology Center. The sample was crushed, sized, and ball-milled to remove attached devitrified glass, and then the biotite was separated from the glass using a Frantz magnetic separator. The resultant biotite separate contained about 20 percent oxidized biotite grains. The altered biotite grains were removed from the fresher, dark-looking grains using an MEI (heavy liquid) density column. The biotite was then put in a distilled water bath in an ultrasonic cleaner to remove any remaining attached devitrified glass.

Argon isotope abundances of gas extracted after total fusion of sample splits were measured on Reynolds-type rare-gas mass spectrometers using isotope dilution by calibrated ^{38}Ar spikes, metered from a pipette system.

Age reduction and calculation of errors were made with an on-line Macintosh computer. The ^{38}Ar calibration was established by control dates on in-house standards JFE 64-29 and GHC305 and are calibrated in turn with interlaboratory standards of known age and by first principles using gas laws, atmospheric abundance and isotopic composition, and the assumption of the invariant volumes in the precisely manufactured air-pipette system.

Potassium analyses were made in duplicate on sample splits with a Zeiss PF-5 flame photometer following procedures described by Carmichael *et al.* (1968).

The one-sigma (1σ) errors that accompany each age analysis incorporate variation calculated in the measurement of 1) duplicate potassium measurements, 2) total ^{40}Ar/^{36}Ar correction, 3) ^{36}Ar/^{38}Ar spike composition, 4) ^{40}Ar/^{38}Ar and ^{38}Ar/^{36}Ar initial ratios, and 5) ^{38}Ar spike calibration and are calculated using standard propagation of error methods.

The weighted average is calculated following procedures described in Taylor (1982).

Decay constants used in the age calculations are those recommended by Steiger and Jager (1977): Decay constants; $\lambda_\epsilon + \lambda_\epsilon' = 0.581 \times 10^{-10}$ yr^{-1}; $\lambda\beta = 4.962 \times 10^{-10}$ yr^{-1}; ^{40}K/K total $= 1.167 \times 10^{-4}$ mol/mol.

Where necessary, all of the isotopic age determinations cited in this paper have been corrected to the new constants of Steiger and Jager (1977).

MEASUREMENTS AND ABBREVIATIONS

The methodology for measuring fossil specimens follows Schultz and Falkenbach (1968), and the values are expressed in millimeters. The dental dimensions have this convention: anteroposterior by buccolingual. Tooth measurements that are approximate due to damage are indicated with the symbol @. Additional abbreviations are: a-p, anteroposterior; b-l, buccolingual; ft., feet; m, meter(s); mm, millimeter(s); Ma, megannum; NALMA, North American Land Mammal Age.

SYSTEMATIC PALEONTOLOGY

Merycoidodontidae Hay, 1902

Sespia sp., cf. *S. californica* (Stock, 1930)

SPECIMEN. LACM 5549, right and left paired dentaries with partial dentition; left M_{2-3} fragments and right P_3–M_3 fragments.

LOCALITY. LACM (CIT) 300, Willard Canyon, South Mountain, Ventura County, California. Precise locality data are available to qualified professionals from the Natural History Museum of Los Angeles County.

AGE AND HORIZON. Arikareean; Sespe Formation; approximately 265 m (870 ft.) below the top of the Sespe.

DESCRIPTION. LACM 5549 is a pair of partial dentaries with worn right P_4–M_3 and worn and damaged left M_{2-3}. The occlusal surfaces are obliterated by extensive wear, yet some dental features may be observed. C: ovate alveolus, no diastema. P_2–P_4 single-rooted. The P_4 paracristid is subparallel to the midsagittal plane and is not sharply deflected from an anteroposterior orientation. M_1: quadratic in occlusal outline with buccal damage. Both anterior molars have lost the occlusal enamel and show the hypoflexid or median valley. M_2: heavily worn quadrate tooth that is significantly larger than M_1. M_3: significantly larger than M_2 and with a prominent hypoconulid. The mental foramina are situated ventral to P_4 and near the dorsoventral midpoint of the dentary. P_1–P_4 are single-rooted with elliptical alveoli. A partial ascending ramus is present.

DISCUSSION. This specimen closely approximates the conditions seen in other dentaries of *Sespia californica* (Stock), although the holotype has a smaller M_3 hypoconulid and the mental foramen is situated 0.5 mm more anteriorly compared to the holotype. Diagnostic characters include a gracile dentary with the postsymphysis at P_3, a deep horizontal ramus, and a high ascending ramus. The crowded and relatively small premolars contrast with the progressively elongate molars. Should further material from this level substantiate this species assignment, then *S. californica* has a stratigraphic range of about 608 to 265 m below the top of the Sespe Formation at South Mountain.

LACM 5549 retains the only ascending ramus known for any of the leptaucheniines from the Sespe Formation. It is damaged, but it appears to be as high as or higher than that found in *S. marianae* Schultz and Falkenbach, 1968. The southern Californian species is the more primitive of the two in its small size, less hypsodont cheek teeth, and relatively uncrowded premolars in comparison to *S. marianae.*

Sespia californica may be the older of the two species of *Sespia* because of its relative primitiveness and its stratigraphic range, which extends well below the Willard Canyon tuff at South Mountain, but the evidence remains inconclusive. There is nothing in the present analysis that eliminates the competing hypothesis that considers the two species geologically contemporaneous.

MEASUREMENTS OF THE SPECIMEN. P_4, 4.2 × 3.0 @; M_1, 4.5 × 3.5 @; M_2, 6.3 × 4.5 @; M_3, 13.0 × 4.8. The depth of the ramus at M_3 is 18.0 mm. The height of ascending ramus at the coronoid notch is estimated to be 40 mm. The length of P_1–M_3 is 38@ mm. The length P_1–P_4 is 14@ mm. The length M_1–M_3 is 23.5 mm.

Some remeasurements of the holotype of *Sespia californica* were found to differ from those published by Schultz and Falkenbach (1968) and are: depth of jaw at anterior edge of M_3, 17.0 mm and length M_1–M_3, 23.5@ mm.

STRATIGRAPHY AND GEOCHRONOLOGY

Based primarily on the stage of evolution of the oreodonts at South Mountain, Stock (1930) considered the South Mountain Local Fauna to correlate with the fossil mammals from the lower "Rosebud" Formation of South Dakota. Wilson (1949) assigned the fauna from the upper 152 m (500 ft.) at South Mountain to the Arikareean NALMA and suggested an age range from Whitneyan to Arikareean for the lower 486 m (1600 ft.). Schultz and Falkenbach (1949, 1954, 1968) correlated the South Mountain Local Fauna with the upper Gering and Monroe Creek faunas of Nebraska. Stirton (1960), in a paper on a marine carnivore, discussed the age of the South Mountain Local Fauna and assigned it to the Arikareean. Savage and Russell (1983) have more recently recalled Wilson's (1949) interpretation and assigned only those fossil mammals from the upper part of the Sespe Formation (Willard Canyon sites) to the Arikareean. Tedford *et al.* (1987) have presented the most recent consensus opinion that the South Mountain Local Fauna is a correlate of the fauna from the Gering Formation of Nebraska.

Much of the controversy regarding the age of the South Mountain Local Fauna is due to the dearth of fossils that are encountered within the thick stratigraphic interval in this area. An oreodont described herein raises the known stratigraphic range of leptaucheniines in the South Mountain section about 61 m (200 ft.) from previous reports and demonstrates the uncertainty regarding the true stratigraphic ranges of the few reported taxa.

WILLARD CANYON TUFF

A study directed toward collecting additional fossil vertebrates from the Sespe Formation at South Mountain resulted in the identification of a tuff about 271 m (890 ft.) below the Sespe–Vaqueros formational contact, 60 m (200 ft.) above the top of Stock's (1934) "Leptauchenid Zone," and about 337 m (1100 ft.) above the type locality of *Sespia californica.* Primary extrusive volcanic rocks are rare in the Sespe Formation and no previous isotopic age analyses have been reported in the literature. The Willard Canyon tuff, so named for the canyon with readily accessible and excellent exposures of this pumiceous tuff, has abundant euhedral biotite in a mudstone matrix as well as pebble to granule-sized, biotite-rich, pumice fragments.

Two argon analyses of the biotite (KA 5590R and 5590R-2), conducted at the Berkeley Geochronology Center, yielded 40.9 and 40.0 percent radiogenic argon, a K content of 6.12 percent for ages of 28.1 ± 0.3 Ma and 28.3 ± 0.37 Ma, respectively. An overall age of 28.2 ± 0.2 Ma (weighted average) is indicated for the Willard Canyon tuff (Table 1). The age of this tuff was erroneously reported as 27.8 Ma in an abstract by Mason and Swisher (1988).

SESPE FORMATION–VAQUEROS FORMATION RELATIONSHIPS

Some discordant geochronologic correlations in the Ventura Basin are evident from the data presently available. The predominantly marine Vaqueros Formation of the Ventura Basin has produced marine megafossils and microfossils of chronologic significance. The marine megafaunas of the South Mountain and Big Mountain areas reported by Loel and Corey (1932) and Corey *in* Cushman and LeRoy (1938) contain *Turritella inezana* Conrad, 1857, *Rapana vaquerosensis* Arnold, 1907, and *Macrochlamys magnolia* (Conrad, 1857). In addition, there are taxa that are not shared by these two faunas. The South Mountain assemblage includes *Crassostrea eldridgei* (Arnold, 1907) and *Dosinia margaritana projecta* Loel and Corey, 1932, but the Big Mountain assemblage has only one restricted species—*Crassostrea vaquerosensis* (Loel and Corey, 1932). All range zones of these taxa are restricted to the "Vaqueros" provincial molluscan stage as provisionally defined by Addicott (1972), and the beds containing them are assigned accordingly. Addicott (1972) correlates the "Vaqueros" Stage with the late Zemorrian and early Saucesian Pacific Coast provincial benthic foraminiferal stages of Kleinpell (1938).

Table 1. Data from ^{40}K-^{40}Ar analyses of the Willard Canyon tuff, South Mountain, Ventura County, California.

Sample number	KA no.	Material dated	Weight (g)	% K (mean)	$^{40}Ar^*$ (mol/g)	$^{40}Ar^*$ (%)	Age (Ma ± 1σ)	Weighted mean (Ma)
86SM1	5590R	Biotite	0.26985	6.163	3.021^{-10}	40.9	28.05 ± 0.30	
	5590R-2	Biotite	0.24477	6.163	3.053^{-10}	40.0	28.34 ± 0.37	28.20 ± 0.2

Decay constants: $\lambda_\epsilon + \lambda_\epsilon' = 0.581 \times 10^{-10}$ yr^{-1}; $\lambda = 4.962 \times 10^{-10}$ yr^{-1}; $^{40}K/K_{total} = 1.167 \times 10^{-4}$.
* Radiogenic ^{40}Ar.

Well-documented late Zemorrian and early Saucesian foraminifera from the Vaqueros Formation of the Big Mountain area provide a direct tie between the foraminiferal and marine molluscan chronostratigraphic disciplines, despite some well-recognized problems with diachronic benthic foraminiferal stage boundaries. The two subdivisions of the Zemorrian Stage (Kleinpell, 1938) have been refined by Tipton *et al.* (1973) and further refined by Kleinpell (1980). Although the Big Mountain microfauna reported by Cushman and LeRoy (1938) is relatively small, it contains *Marginulina dubia* Neugeboren, 1851, and *Nonion incisum kernensis* Kleinpell, 1938, which, by Kleinpell's (1980) criteria, are indicative of the upper part of the Zemorrian Stage (*Uvigerina sparsicostata* zone). Both of these taxa are restricted to this zone and no taxa of the Saucesian were reported from this area by Cushman and LeRoy (1938). Tipton *et al.* (1973) reaffirmed the interpretation of Cushman and Leroy (1938). In western Ventura County, a single specimen of a cricetid rodent (UCMP 96289) was found about 117 m (383 ft.) stratigraphically above the base of the Rincon Shale and within the reference section of the *Uvigerina sparsicostata* zone. Direct associations between continental fossil mammals and marine microfaunas are rarely reported but, unfortunately, this isolated specimen (UCMP 96289) is insufficient to provide a direct correlation between a North American Land Mammal Age and the "type" Zemorrian Stage. Marine–nonmarine faunal correlations in the Ventura Basin must be accomplished by less direct means at this time.

It may be recalled that Poore (1980) has a compelling argument for recognizing diachroneity for the Zemorrian–Saucesian boundary when the planktic foraminiferal zonation of the California Paleogene is used as a standard of reference. Blake (1983) has presented a bathymetric study based on benthic foraminifera from the Vaqueros Formation in the Big Mountain area and presented further suggestions for diachroneity of the Zemorrian–Saucesian boundary. According to Blake (1983), the lowest beds of the Vaqueros Formation in this area may be Zemorrian, whereas samples from higher in the section, and stratigraphically equivalent to the samples of Cushman and LeRoy (1938), positively indicate reference to the lower part of the Saucesian Stage. These data lend a caveat to the approximate date of 23 Ma for the Zemorrian–Saucesian boundary as determined by Turner (1970) because the common-stage boundary is apparently significantly diachronic and, therefore, in need of redefinition. The foraminiferal beds of the Vaqueros Formation in the vicinity of Big Mountain are interbedded with the "Vaqueros" Stage marine megafauna.

The Vaqueros Formation in the Big Mountain area has a stratigraphic thickness of approximately 447 m (1470 ft.). The lowest 91.5 m (300 ft.) is a massive sandstone that has produced an insubstantial sample of fossil marine invertebrates and rare marine and continental vertebrates. The diagnostic fossil taxa in this area have been collected from the middle and upper parts of the Vaqueros section. Although the upper 161 m (530 ft.) of the Vaqueros Formation is either upper Zemorrian or lower Saucesian and "Vaqueros" in age, the lowermost 195 to 286 m (640 to 940 ft.) have not yielded any foraminiferal data and cannot be confidently assigned to any of Addicott's (1972) revised marine molluscan stages. Kleinpell and Weaver (1963), however, have indirectly assigned this lower interval to the lower part of their "Vaqueros" Stage based on the presence of *Turritella inezana sespeensis* Arnold, 1907, and *Kewia fairbanksi* (Arnold, 1907). The upper Zemorrian is a correlative of the lower "Vaqueros" according to these authors. This problematic lower "Vaqueros" interval is not presently recognized at South Mountain, partly because published foraminiferal data for the Vaqueros Formation of South Mountain are lacking.

The age-diagnostic invertebrate fossils of the Big Mountain and South Mountain areas provide no more than a minimum age for the upper parts of the underlying Sespe Formation because the Vaqueros Formation rests unconformably on the Sespe Formation in both of these areas (Canter, 1974; Yeats, 1987). The Vaqueros Formation at South Mountain reaches a maximum thickness of 335 m (1100 ft.) (Baddley, 1954), and the marine megafauna that was reported by Loel and Corey (1932) was collected from the lowest 30 m.

Present interdisciplinary paleontologic correlations do not support the contention that the Alamos Canyon Local Fauna, from the uppermost beds of the Sespe Formation at Big Mountain, is overlain by foraminifera referable to the lower part of the Zemorrian Stage. The Zemorrian Stage is regionally tied to calcareous nannoplankton zones CP18 and

CP19 and possibly planktic foraminiferal zone ?P22 (McDougall, 1983). The succeeding Saucesian Stage has been recorded in association with nannoplankton referable to the upper part of zone CN1 (Newell *in* Lagoe, 1988). Other workers (Poore, 1980; Poore and Bukry, 1983) have reported microfossil associations that suggest the lower part of the Zemorrian Stage is correlative with zones CP18 and possibly CP19 as well as zones P19, P20, and possibly ?P21. According to Berggren *et al.* (1985), the minimum age of the early-late Zemorrian transition, if correlative with P21 and CP19, corresponds in age to the earliest Arikareean and can be no older than about 28 to 29 Ma. The Willard Canyon tuff date of 28.2 Ma, the overlying 264 m of Sespe Formation sediments, and the "Vaqueros" Stage fauna in the overlying Vaqueros Formation support the inference that the Vaqueros Formation at South Mountain is no older than late Zemorrian (*Uvigerina sparsicostata* chron). This interpretation is in agreement with the conclusions of Tipton *et al.* (1973) and, indirectly, with the Arikareean Age assignment of the South Mountain Local Fauna by Wilson (1949) and Schultz and Falkenbach (1949).

If the lower Zemorrian assignment given to the lower part of the Vaqueros Formation by Tipton *et al.* (1973) is accepted, then the fossil mammals from the subjacent Sespe Formation could not be younger than Orellan or possibly Whitneyan following the chronostratigraphic correlations of Berggren *et al.* (1985). The combined available chronostratigraphic data suggest that the early-late Zemorrian boundary is approximately coincident with the Orellan–Whitneyan boundary and precludes the possibility of an Arikareean "Age" for the Alamos Canyon Local Fauna. This discordance is resolvable either by recognizing the upper Sespe Alamos Canyon Local Fauna as Whitneyan (or older) or by recognizing the lowest beds of the Vaqueros Formation as upper Zemorrian or lower Saucesian, as Blake (1983) has suggested.

Wilson (1949) considered a Whitneyan North American Land Mammal Age assignment for the Alamos Canyon Local Fauna on the basis of the primitive stage of evolution of a single specimen, LACM (CIT) 3538, which he referred to *Archaeolagus* (Cope, 1881). Dawson (1958) reaffirmed his systematic conclusion. Although *Archaeolagus* first occurs in the Whitneyan of the Great Plains, Wilson (1949) refrained from assigning this fauna to the Whitneyan. A leptaucheniine that had been found approximately 305 m (1000 ft.) stratigraphically below the *Archaeolagus* specimen suggested to Wilson a correlation with the Arikareean "leptauchenid zone" of South Mountain and thereby precluded a Whitneyan Age for the Alamos Canyon Local Fauna.

Assignment of the fossil mammals from the upper 305 m (1000 ft.) of the Big Mountain–Alamos Canyon section of the Sespe Formation to the Whitneyan Age is consistent with present chronostratigraphic data. The age assignments of the mammalian and marine invertebrate fossils in the upper part of the Sespe Formation and the lower to middle Vaqueros Formation in this area are in accord following this rationale, but the lost leptaucheniine mentioned by Wilson (1949) would have to be recognized as older than the oreodonts of the "leptauchenid zone" of South Mountain. Because this specimen is presumed lost and not available for study, any further interpretation is conjectural. Alternatively, the recognition of the lowest beds of the Vaqueros Formation as late Zemorrian or early Saucesian provides further constraints, following Berggren *et al.* (1985) and McDougall (1983), that are in agreement with the mammalian and foraminiferal age assignments of Wilson (1949) and Blake (1983), respectively. In this case, the Alamos Canyon Local Fauna would more likely be Arikareean and correlative with the South Mountain Local Fauna.

ARIKAREEAN-CENOZOIC EPOCH CORRELATION

Lander (1983) has contested some previous correlations of the early Arikareean with the latest Oligocene and early Miocene (Berggren *et al.*, 1978) and has proposed an early Arikareean NALMA–Refugian Pacific Coast benthic foraminiferal stage–late Eocene correlation. His interpretation is based on a suggested stratigraphic correlation between three fossil vertebrate specimens from the Sespe Formation in the Santa Ynez Mountains (western Transverse Ranges, Santa Barbara County) and Narizian ("Eocene") benthic foraminiferal faunas from the Sacate Formation. More defensible age estimates of Tertiary epoch boundaries and chronostratigraphic correlations are discussed in Berggren *et al.* (1985) and conflict with those proposed by Lander (1983).

The suggestion by Lander (1983:148) that the early Arikareean faunas from the Sespe Formation may be as old as 35 Ma conflicts with the isotopic age data from the Willard Canyon tuff. Because the isotopic ages for tuffs from the base of the Gering Formation (Table 2) are essentially identical to the age determination from the South Mountain Local Fauna (28.2), a 28 to 29 Ma age estimate is suggested for the early Arikareean NALMA. Isotopic age data from other Gering Formation correlatives (Tedford *et al.*, 1987) and the 32 to 36 Ma age data from volcanic rocks that are associated with Chadronian faunas in west Texas and Wyoming (reviewed by Wilson, 1986) are discordant with Lander's (1983) age estimate for the Arikareean.

Marine–nonmarine correlations in the Paleogene section of San Diego, California, supply further evidence for a post-Eocene age for the Arikareean NALMA (see May and Warme, 1987, for most recent review of San Diego "Eocene" stratigraphy). The Ardath Shale in the San Diego embayment has produced an early Uintan–late Bridgerian fauna

Table 2. Compilation of the published age determinations for the lower part of the Gering Formation, northwestern Nebraska. Data from Obradovich *et al.* (1973) and Naeser *et al.* (1980).

Locality	Age (Ma)	Mineral	Method	Analyzer
Roundhouse Rock	28.7 ± 0.7	Biotite	^{40}K-^{40}Ar	Obradovich[1]
Helvas Canyon	27.7 ± 0.7	Biotite	^{40}K-^{40}Ar	Obradovich[1]
Helvas Canyon	27.8 ± 3.1	Zircon	Fission track	Not given[1]
Helvas Canyon	27.6 ± 0.6	Zircon	Fission track	Izett[2]
Helvas Canyon	28.8 ± 0.8	Zircon	Fission track	Naeser[2]
"Twin Sister's"	27.7 ± 0.6	Sanidine	^{40}K-^{40}Ar	Obradovich[1]

[1] Obradovich *et al.*, 1973.

[2] Naeser *et al.*, 1980.

(Golz, 1976) as well as nannoplankton referable to CP12b (Bukry, 1980). If the marine Priabonian Stage of Europe is correlative with CP15 (Berggren *et al.*, 1985), then Lander's (1983) correlation of the Arikareean with the Eocene would inexplicably restrict the Uintan, Duchesnean, Chadronian, Orellan, and Whitneyan NALMAs within two nannoplankton zones (CP13 and CP14).

These data call into question Lander's (1983) lithologic and paleontologic correlations within the Santa Ynez Mountains. His conclusion that *Sespia* sp. from the Sespe Formation can be physically correlated with the marine invertebrate fauna from the Sacate Formation is suspect. Further studies in the structurally complex Santa Ynez Mountains are necessary to resolve the anomolous correlations presented by Lander (1983).

With respect to the "Unnamed local fauna" of Lander (1983) from the upper part of the Sespe Formation near Moorpark, Lander's (1983:143) "late Eocene? (Priabonian)" age assignment for this part of the Sespe is likewise not supported by the present evidence.

SOUTH MOUNTAIN–GREAT PLAINS CONTINENTAL CORRELATION

Scattered fossil mammals from the upper part of the Sespe Formation at South Mountain (Table 3) include *Sespia californica* Stock, ?*Desmatochoerus thurstoni* (Stock, 1934), *Mesoreodon hesperus* (Stock, 1930) (following Schultz and Falkenbach, 1949, 1954, 1968), and geomyid rodents (Wilson, 1949). These taxa have affinities with the oreodonts and rodents that have been described from the Gering Formation of Nebraska and the Sharps Formation of South Dakota. The holotype of *S. californica* was found approximately 337 m (1100 ft.) below the Willard Canyon tuff and is, therefore, demonstrably older than 28.2 Ma. Ongoing studies of the stratigraphy and structure of the Sespe Formation in the South Mountain area may require modification of the stratigraphic interpretations presented in Figure 2 but the general stratigraphic relationships appear to be correct. The isotopic age determinations from the Gering Formation are discussed below.

Sespia marianae Schultz and Falkenbach, 1948, including the holotype from Wildcat Ridge of western Nebraska, was recovered from a level near the base of the Gering Formation and stratigraphically in association with dated tuffs. A number of K-Ar and fission track dates have been made on minerals from these tuffs. Obradovich *et al.* (1973) reported a ^{40}K-^{40}Ar age on biotite from the Carter Canyon Ash in Helvas Canyon of 27.7 ± 0.7 Ma. The same ash yielded a fission track age on zircon of 27.8 ± 3.1 Ma. Naeser *et al.* (1980) reported additional fission track ages on zircon of 27.6 ± 0.6 Ma (analysis by Izett) and 28.8 ± 0.8 Ma (analysis by Naeser).

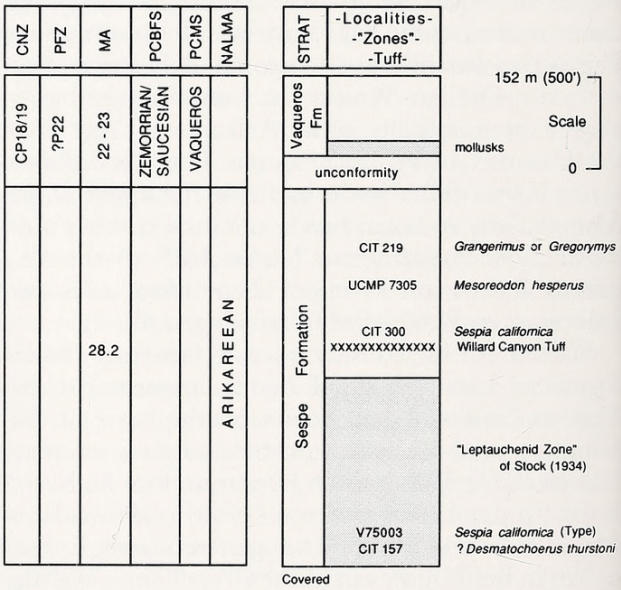

Figure 2. Generalized stratigraphic column and correlation chart for the Sespe Formation, South Mountain, California. Certain localities and taxa with less precise stratigraphic positions are not plotted; see faunal list (Table 3) for additional paleontologic and stratigraphic data. Abbreviations are as follows: NALMA, North American Land Mammal Age; PCMS, Pacific Coast Molluscan Stage; PCBFS; Pacific Coast Benthic Foraminiferal Stage; MA, megannum; PFZ, Planktic Foraminiferal Zone; CNZ, Calcareous Nannofossil Zone. Data from Stock (1930, 1934, unpublished), Wilson (1949), McDougall (1983), Poore and Bukry (1983), Yeats (1987), Turner (1970), and this paper.

A tuff from the lower part of the Gering Formation at Roundhouse Rock yielded a ^{40}K-^{40}Ar age on biotite of 28.7 ± 0.7 Ma (Obradovich *et al.*, 1973). Although the tuffs from Roundhouse Rock and Helvas Canyon are from the lower part of the Gering Formation, it is not certain that they represent exposures of the same tuff, because outcrop exposures do not allow physical correlation of the two tuffs.

In addition to these dates, sanidine-bearing pumice from the middle part of the Gering Formation yielded a ^{40}K-^{40}Ar age of 27.7 ± 0.6 Ma (Obradovich *et al.*, 1973). This pumice-bearing unit crops out stratigraphically above the dated tuffs at both Roundhouse Rock and Helvas Canyon and is known as the "Twin Sister's Pumice Conglomerate."

Tedford *et al.* (1987) list some of these ages for the calibration of the beginning of Arikareean time. A complete list of these data (Table 2) suggests a bimodal distribution, the ages being either approximately 28.7 or 27.7 Ma. The reason for the bimodal distribution of these ages was not given by these authors, and its explanation is not within the scope of this study. As a result, given the discrepancy in these age determinations, it is not possible to be certain whether the Willard Canyon tuff is older or younger than the basal part of the Gering Formation of Nebraska. If the tuffs at Roundhouse Rock and Helvas Canyon represent the same eruptive event, then the average of the biotite dates from these two localities and the average of the two better zircon dates from Helvas Canyon would be 28.2 ± 0.5 Ma, an age consistent with the age of the Willard Canyon tuff.

Table 3. Fossil vertebrate faunal list by locality for the South Mountain Local Fauna, Ventura County, California.

	Upper 305 m (1000 ft.)
UCMP 7305	?*Mesoreodon hesperus* (Stock, 1930)
UCMP 7304	Leptaucheniinae [lost?]
CIT 158	Hypertragulidae
CIT 160	Leptaucheniinae
CIT 167	*Diceratherium* sp.
	Leptaucheniiae
CIT 219	*Grangerimus* sp. or *Gregorymys* sp.
?CIT 166	*Sespia* sp.
V82003	Hypertragulidae
	Approximately 200 to 335 m (650 to 1100 ft.) below top
CIT 300	*Sespia* cf. *S. californica* (Stock, 1930)
	Approximately 335 to 640 m (1100 to 2100 ft.) below top
	"Leptauchenid Zone" of Stock
CIT 157	?*Desmatochoerus thurstoni* (Stock, 1934)
	Sespia californica (Stock, 1930)
	Sespia sp.
	Leptaucheniinae
CIT 159	Leptaucheniinae
CIT 220	?*Mookomys bodei* Wilson, 1949
V6101	*Sespia californica* (Stock, 1930)
V6102	*Sespia californica* (Stock, 1930)
V75003	*Sespia californica* (Stock, 1930)
V67114	Testudinidae
?V2601	*Sespia californica* (Stock, 1930)

CONCLUSIONS

The presence of the oreodont *Sespia californica* (Stock) and the 28.2 ± 0.2 Ma isotopic age determination associated with the South Mountain Local Fauna provide evidence for an "early" Arikareean Age for the fauna of the lowest exposed beds of the Sespe Formation at South Mountain (Fig. 2). The sparse fossil mammal sample known for the upper part of the Sespe Formation in this area is correlative in age to the fauna from the Gering Formation or possibly the fauna from the overlying Monroe Creek Formation—that is, either "early" or "middle" Arikareean. The age of the top of the Sespe Formation is constrained by the "Vaqueros" molluscan assemblage that has been recovered from the unconformably overlying Vaqueros Formation. The "Vaqueros" Age is correlative with the late Zemorrian and early Saucesian ages. Isotopic age determinations of 22 to 23 Ma are associated with the Zemorrian–Saucesian boundary and provide an estimate of the minimum age of the uppermost Sespe beds.

The Alamos Canyon Local Fauna, which includes all specimens from the upper 305 m (1000 ft.) of the Sespe Formation in the Big Mountain area, is suspected of being no older than Arikareean. Evidence for this interpretation is provided by the "Vaqueros" marine molluscan assemblage and the early Saucesian benthic foraminiferal assemblage that have been reported from the overlying Vaqueros Formation in this area.

The best fit of the combined evidence from the various geochronologic disciplines suggests an approximate age equivalence for the mammalian faunas of the uppermost beds of the Sespe Formation at South Mountain and Big Mountain, Ventura County, California.

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ADDENDUM

Recent work by Howard (1989), published since the submission of this paper, provides additional field data pertaining to the correlation of the Refugian (marine) and the Arikareean (nonmarine) faunas proposed by Lander (1983). In the western Santa Ynez Range, Howard (1989) recognized a major unconformity in the nonmarine Sespe Formation a few meters below the fossil vertebrate locality (V5813) that was essential to Lander's Eocene age designation for the Arikareean North American Land Mammal Age. The lower part of the Sespe Formation, below the unconformity, grades laterally into the marine Gaviota Formation of Refugian (late Eocene) age (Howard, 1989). Stratigraphically above the unconformity, the upper part of the Sespe contains the Arikareean (late Oligocene) fauna and grades laterally into the sparsely fossiliferous Alegria Formation (or Alegria member of the Vaqueros Formation following Rigsby [1988]). The duration of the unconformity is suggested by the lack of latest Eocene through mid-Oligocene (Chadronian-Whitneyan) nonmarine fossils in the upper Sespe section. The unconformity is attributed by Howard (1989) to global drop in sea level at 31 Ma. This new data corroborates our conclusions proposed here, based on radioisotopic and paleontologic data, that the Arikareean faunas of the upper part of the Sespe Formation are late Oligocene in age.

LITERATURE CITED

Addicott, W.O. 1972. Provincial middle and late Tertiary molluscan stages, Temblor Range, California, pp. 1–26. In: *Proceedings of the Pacific Coast Miocene Biostratigraphic Symposium,* E.H. Stinemeyer and C.C. Church, eds. Society of Economic Paleontologists and Mineralogists, Pacific Section.

Baddley, E.R. 1954. Geology of the South Mountain oil field, Ventura County, California. In: *Geology of Southern California.* California Division of Mines, Bulletin 170, Map Sheet 29.

Berggren, W.A., D.V. Kent, J.J. Flynn, and J.A. Van Couvering. 1985. Cenozoic geochronology. *Bulletin of the Geological Society of America* 96:1407–1418.

Berggren, W.A., M.C. McKenna, J. Hardenbol, and J.D. Obradovich. 1978. Revised Paleogene polarity time scale. *Journal of Geology* 86:67–81.

Blake, G.H. 1983. Benthic foraminiferal paleoecology and biostratigraphy of the Vaqueros Formation, Big Mountain area, Ventura County, California, pp. 173–182. In: *Cenozoic Geology of the Simi Valley Area, Southern California.* R.L. Squires and M.V. Filewicz, eds. Society of Economic Paleontologists and Mineralogists, Pacific Section, Fall Fieldtrip Guidebook.

Bukry, J.D. 1980. Coccolith correlation for Ardath Shale, San Diego County, California. *United States Geological Survey, Professional Paper* 1175:496.

Canter, N.W. 1974. *Paleogeology and Paleogeography of the Big Mountain Area, Santa Susana, Moorpark, and Simi Quadrangles, Ventura County, California.* Masters thesis, Ohio University, Athens, 58 pp.

Carmichael, I.S.E., J. Hampel, and R.N. Jack. 1968. Analytical data on the U.S.G.S. standard rocks. *Chemical Geology* 3:59–64.

Cushman, J.A., and L.W. LeRoy. 1938. A microfauna from the Vaqueros Formation, lower Miocene, Simi Valley, Ventura County, California. *Journal of Paleontology* 12:117–126.

Dawson, M.R. 1958. Later Tertiary Leporidae of North America. *University of Kansas Paleontological Contributions* 6:1–75.

Durham, J.W., R.H. Jahns, and D.E. Savage. 1954. Marine–nonmarine relationships in the Cenozoic section of California, pp. 59–71. In: *Geology of Southern California,* R.H. Jahns, ed. California Division of Mines Bulletin 170, chapter 3.

Golz, D.J. 1976. Eocene Artiodactyla of southern California. *Natural History Museum of Los Angeles County, Science Bulletin* 26:1–85.

Howard, J. L. 1989. Conglomerate clast populations of the upper Paleogene Sespe Formation, southern California, pp. 269–280. In: *Conglomerates in Basin Analysis: A Symposium Dedicated to A. O. Woodford,* I. P. Colburn, P. L. Abbott, and J. Minch, eds. Pacific Section, Society of Economic Paleontologists and Mineralogists, Volume 62.

Kleinpell, R.M. 1938. *Miocene Stratigraphy of California.* American Association of Petroleum Geologists, Tulsa, Oklahoma, 450 pp.

———. 1980. History of stratigraphic paleontology of West Coast Tertiary, pp. 4–53. In: *The Miocene Stratigraphy of California Revisited,* R.M. Kleinpell, ed. American Association of Petroleum Geologists Studies in Geology, no. 11.

Kleinpell, R. M., and D.W. Weaver. 1963. Oligocene biostratigraphy of the Santa Barbara embayment. *University of California Publications in Geological Sciences* 43:1–50.

Lander, E. B. 1983. Continental vertebrate faunas from the upper member of the Sespe Formation, Simi Valley, California and the terminal Eocene event, pp. 142–154. In: *Cenozoic Geology of the Simi Valley Area, Southern California,* R. L. Squires, ed. Pacific Section, Society of Economic Paleontologists and Mineralogists, Field Guide.

Lagoe, M.B. 1988. An outline of foraminiferal biofacies in the Soda Lake Shale Member, Vaqueros Formation, Cuyama Basin, California, pp. 21–28. In: *Tertiary Tectonics and Sedimentation in the Cuyama Basin, San Luis Obispo, Santa Barbara, and Ventura Counties, California,* W.J.M. Bazeley, ed. Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Guide, Book 59.

Loel, W., and W.H. Corey. 1932. The Vaqueros Formation, lower Miocene of California, 1, Paleontology. *University of California Publications, Bulletin of the Department of Geological Sciences* 22:31–410.

Mason, M.A., and C.C. Swisher. 1988. New evidence for the age of the South Mountain Local Fauna, Ventura County, California, and its relationship to marine geochronology. *Geological Society of America [Cordilleran Section], Abstracts with Programs* 20(3):211.

May, J.A., and J.E. Warme. 1987. Synchronous depositional phases in west coast basins: eustasy or regional tectonics?, pp. 24–46. In: *Cenozoic Basin Development of Coastal California,* R.V. Ingersoll and W.G. Ernst, eds. Prentice-Hall, Englewood Cliffs, New Jersey.

McDougall, K.A. 1983. Upper Eocene to lower Miocene benthic foraminifers from the Santa Cruz Mountains area, California, pp. 61–74. In: *Studies*

in Tertiary Stratigraphy of the California Coast Ranges, E.E. Brabb, ed. United States Geological Survey Professional Paper 1213.

Naeser, C.W., G.A. Izett, and J.D. Obradovich. 1980. Fission-track and K-Ar ages of natural glasses. *United States Geological Survey Bulletin* 1489:1–31.

Obradovich, J.D., G.A. Izett, and C.W. Naeser. 1973. Radiometric ages of volcanic ash and pumice beds in the Gering Sandstone (earliest Miocene) of the Arikaree Group, southwestern Nebraska. *Geological Society of America, Abstracts with Programs* 5:499–500.

Poore, R.Z. 1980. Age and correlation of California Paleogene benthic foraminiferal stages. *United States Geological Survey Professional Paper* 1162-C:1–8.

Poore, R.Z., and D. Bukry. 1983. Eocene to Miocene calcareous plankton from the Santa Cruz Mountains and northern Santa Lucia Range, California, pp. 49–61. In: *Studies in Tertiary Stratigraphy of the California Coast Ranges,* E.E. Brabb, ed. United States Geological Survey Professional Paper 1213.

Rigsby, C. A. 1988. Lithostratigraphy of the Vaqueros and adjacent formations in the Santa Ynez Ranges: A re-evaluation in progress, pp. 129–133. In: *Paleogene Stratigraphy, West Coast of North America,* M. V. Filewicz and R. L. Squires, eds. Pacific Section, Society of Economic Paleontologists and Mineralogists, Volume 58.

Savage, D.E., and D.E. Russell. 1983. *Mammalian Paleofaunas of the World.* Addison-Wesley, Reading, Massachusetts.

Schultz, C.B., and C.H. Falkenbach. 1949. Promerycochoerinae, a new subfamily of oreodonts. *Bulletin of the American Museum of Natural History* 93: 69–198.

———. 1954. Desmatochoerinae, a new subfamily of oreodonts. *Bulletin of the American Museum of Natural History* 105:143–256.

———. 1968. The phylogeny of the oreodonts, parts 1 and 2. *Bulletin of the American Museum of Natural History* 139:1–498.

Steiger, R.H., and E. Jager. 1977. Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters* 36:359–362.

Stirton, R.A. 1960. A marine carnivore from the Miocene Clallam Formation, Washington. *University of California Publications in Geological Sciences* 36: 345–368.

Stock, C. 1930. Oreodonts from the Sespe deposits of South Mountain, Ventura County, California. *Carnegie Institution of Washington Publications* 404: 27–42.

———. 1934. On the occurrence of an oreodont skeleton in the Sespe of South Mountain, California. *Proceedings of the National Academy of Sciences* 20:518–523.

———. 1948. Pushing back the history of land mammals in western North America. *Geological Society of America, Bulletin* 59:327–332.

Taylor, J.R. 1982. *An Introduction to Error Analysis.* Science Books (Oxford University Press), Mill Valley, California, 270 pp.

Tedford, R.H., T. Galusha, M. F. Skinner, B. E. Taylor, R. W. Fields, J. R. Macdonald, J. M. Rensberger, S. D. Webb, and D. P. Whistler. 1987. Faunal succession and biochronology of the Arikareean through Hemphillian interval (late Oligocene through earliest Pliocene epochs) in North America, pp. 153–210. In: *Cenozoic Mammals of North America,* M.O. Woodburne, ed. University of California Press, Berkeley.

Tipton, A., R.M. Kleinpell, and D.W. Weaver. 1973. Oligocene biostratigraphy, San Joaquin Valley, California. *University of California Publications in Geological Sciences* 105:1–81.

Turner, D.L. 1970. Potassium-argon dating of Pacific Coast Miocene foraminiferal stages. *Geological Society of America Special Paper* 124, pp. 91–129. In: *Radiometric Dating and Paleontologic Zonation,* O. L. Bandy, ed.

Yeats, R.S. 1987. Changing tectonic styles in Cenozoic basins of southern California, pp. 284–298. In: *Cenozoic Basin Development of Coastal California,* R.V. Ingersoll and W.G. Ernst, eds. Prentice-Hall, Englewood Cliffs, New Jersey.

Wilson, J.A. 1986. Stratigraphic occurrence and correlation of early Tertiary vertebrate faunas. Trans-Pecos Texas: Agua Fria–Green Valley areas. *Journal of Vertebrate Paleontology* 6:350–373.

Wilson, R.W. 1949. Rodents and lagomorphs of the upper Sespe. *Carnegie Institution of Washington Publications* 584:51–65.

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