

# Petroleum Systems and Geologic Assessment of Oil and Gas in the San Joaquin Basin Province, California

## Chapter 4

# California Cenozoic Biostratigraphy—Paleogene

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## Abstract

The time transgressive nature of the California benthic foraminiferal stages is in most cases the result of poor taxonomy, use of local species ranges, and a lack of understanding about the type sections. Correcting these problems allows the stages to be consistently applied and enhances their ability to identify coeval strata. Each stage is identified by the first and last appearances of selected cosmopolitan benthic foraminiferal species and of reliable local species. Although further study is needed, the stages correlate with the international time scale. The revised age interpretation of the stages suggests that the Cheneyian Stage is coeval with planktic zone P1 through P3, the Ynezian Stage is coeval with planktic zone P4, the Bulitian Stage is missing in most section but when present is coeval with zones P5 and P6a, the Penutian Stage is coeval with planktic zones P6b through early P9 (no younger than the overlap between P9 and CP11), the Ulatisian Stage is coeval with P9

(younger than CP11) through P11, the Narizian Stage is coeval with zones P12 through P15, and the Refugian Stage is coeval with zones P16 and P17.

## Introduction

Micropaleontology in California evolved rapidly in the 20<sup>th</sup> century with the exploration for oil and the need for a biostratigraphic framework based on the abundant benthic foraminifers found in the sedimentary strata. Schenck and Kleinpell (1936) defined the first stage. Their Refugian Stage was recognized by both molluscan and benthic foraminiferal species. This was followed by the identification of the Miocene Stages and Zones by Kleinpell (1938), early Cenozoic zones based primarily on subsurface data of Laiming (1940, 1943), the early Paleocene, Cheneyian Stage of Goukoff (1945; Loeblich, 1958), Pliocene and Pleistocene Stages (Wissler, 1943; Natland, 1952; Wissler, 1958), and finally the lower Tertiary Stages and zones of Malory (1959). These stages were defined by type sections and the zones were identified by the first, last, and (or) common occurrence of diagnostic benthic foraminiferal species found in the type sections. With the exception of the Laiming zones, type sections were identified for each stage and zone. Subsequent planktic microfossil studies demonstrated that the benthic foraminiferal stages and zones are time transgressive (Bramlette and Sullivan, 1961; Sullivan, 1965; Steineck and Gibson, 1971; Schmidt, 1975; Gibson, 1976; Poore, 1976; Bukry and others, 1977; Warren and Newell, 1980). The time transgressive nature of the stages and zones was further demonstrated by paleomagnetic studies, which support the conclusions based on planktic microfossils (Bottjer and others, 1991; Prothero, 2001b).

With varying degrees of success, micropaleontologists attempted to revise selected stage and zone criteria to accommodate the transgressive nature of the stages and zones and the ecologic restrictions of the diagnostic species (Kleinpell, 1980; McDougall, 1980; Tipton, 1980; Almgren and others, 1988). Most of this work focused on an individual section and (or) stage, rather than looking at a broader interval of

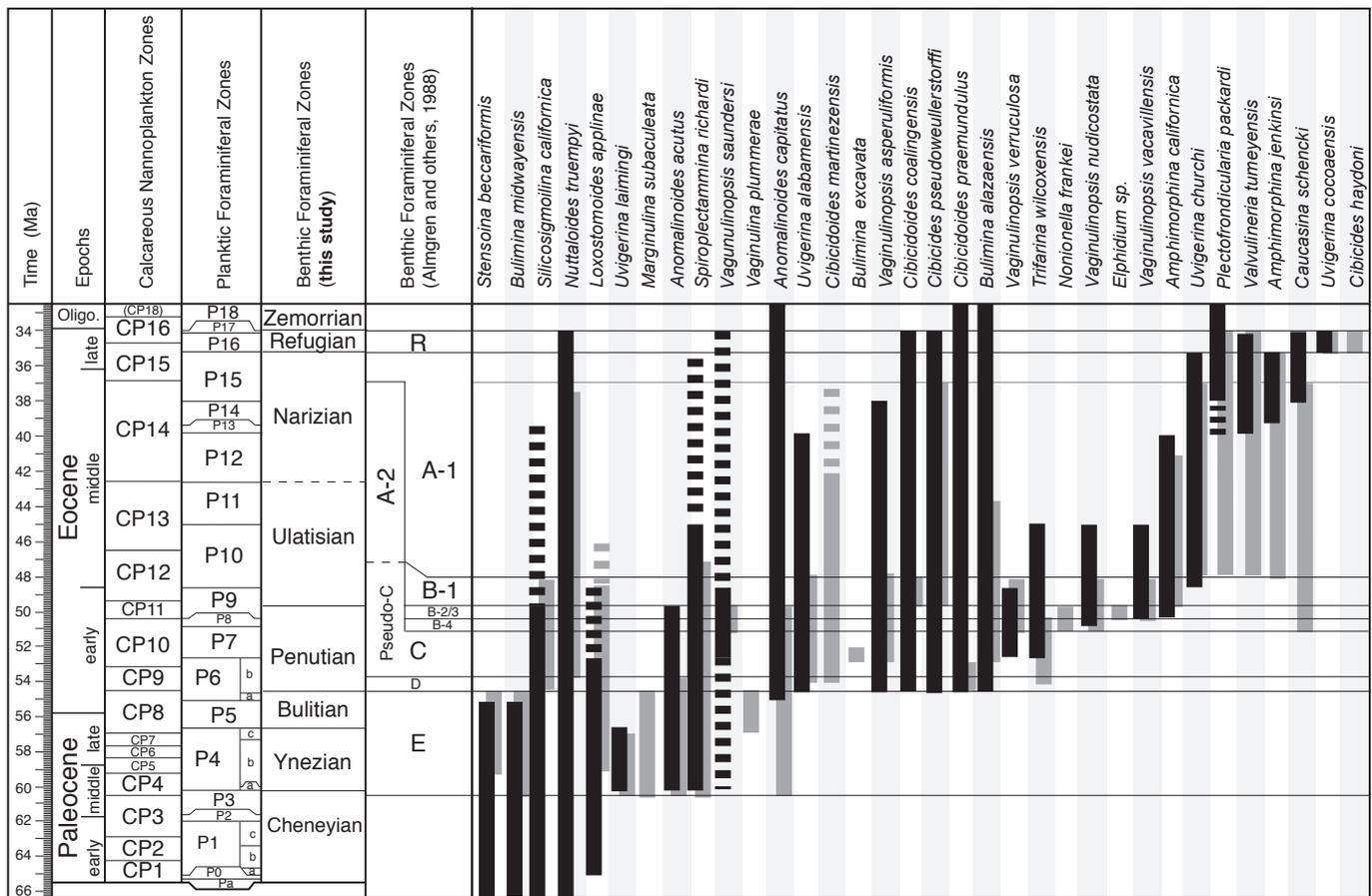
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time or geographic region. Unocal paleontologists (Almgren and others, 1988) discussed problems with the lower Tertiary Stages and zones of Mallory (1959) and proposed a revision using a modified version of the Laiming zones. They found that Mallory's type sections were not clearly identified (geographically or stratigraphically), did not represent continuous deposition, stages and their zones were frequently not the same age, and fossil lists were never published from several of the type sections. Although the modified Laiming zones proposed by Almgren and others (1988) are based on several sections, account for ecologically restricted species, and are tied to a widely used calcareous nannoplankton zonation (Okada and Bukry, 1980; Haq and others, 1987a), they used outdated taxonomy and local or regional ranges for the diagnostic species rather than global ranges (fig. 4.1). Consequently, the zones continue to be time transgressive and strongly influenced by ecologic control. Taxonomy, although not mentioned specifically by Almgren and others (1988), is a critical problem with the Mallory (1959) zonation; much of Mallory's work was based on University of California

graduate theses and there is very little taxonomic consistency between the various studies.

Although planktic microfossils are also present in California marine sections, they are less common and benthic foraminifers are the dominant microfossil group. Thus, there is still a need for a reliable biostratigraphy that can be correlated to international chronologies (for example, Berggren and others, 1995; Gradstein and others, 2004; Gradstein and Ogg, 2005), especially as research efforts become more global in extent. The continued demands for not only age interpretations but also for correlation with international chronologies have led to the biostratigraphic framework presented here (fig. 4.2).

The purpose of this study is to document the Paleogene portion of the biostratigraphic framework presented. This is accomplished by examining the original definitions and type sections of the stages and zones, suggesting revisions, and identifying areas for further work. Each of the type Paleogene sections was reexamined to correct the taxonomy either through direct examination of the specimens or through a literature study. The age interpretations based on benthic foraminiferal



**Figure 4.1.** Ranges of key Paleogene taxa according to Almgren and others (1988) are shown in grey; total ranges of these cosmopolitan species are shown in black. Species names used by Almgren and others (1988) and Laiming (1939, 1940, 1943) were modified to conform to current taxonomy (see appendix 4.1). Oligo., Oligocene.

faunas are reconsidered in light of the ranges of the cosmopolitan species, stratigraphy, the original intent of the biostratigraphers, and what could be realistically documented at this time. Problems encountered during this study include determining what each California Paleogene Stage represents and unraveling the various stratigraphic and taxonomic problems related to the existing zonations. These problems are complicated because (1) several zonal schemes are entrenched in California geology, (2) there are numerous informal modifications, (3) taxonomy of California benthic foraminiferal species is in serious need of revision, and (4) California geology is complex.

In the biostratigraphic framework discussed here, the Mallory (1959), Kleinpell (1938), and Natland (1952) stage names are retained. The zones of Laiming (1939, 1940, 1943) are not used because they cover only a portion of the Cenozoic, only have summary faunal lists, and no type sections were provided for the zones. The modified Laiming zones of Almgren and others (1988) are not used because although sections were identified where their zones can be observed, no faunal lists or references to faunal lists were provided, and cosmopolitan species ranges were not used.

The original intent of the California biostratigraphers was to develop a chronostratigraphic framework that allowed recognition of time intervals (that is, stages) with biostratigraphic zones based on fossils and in this case benthic foraminifers (see Hedberg, 1976; Murphy and Salvador, 1999). Unfortunately, the Opellian zones used by the early Californian biostratigraphers are subjective and loosely defined; transition intervals are often needed between the zones. Opellian zones are no longer widely used (Hedberg, 1976; Berggren and Miller, 1989). The loose definition of the California zones and the difficulty in consistently recognizing them has contributed considerably to the time transgressiveness of the California stages.

Systematic studies of benthic foraminifers have resulted in a better understanding of not only the taxonomy but also the ranges and ecologic tolerances of species (Tjalsma and Lohmann, 1983; Boersma, 1984; van Morkhoven and others, 1986). This wealth of systematic data, when applied to the California faunas, provides a more cohesive taxonomy, recognition of cosmopolitan species, and a better understanding of species distribution in time and space. The results of this phase of the study are summarized in appendix 4.1. The biostratigraphic zonation is then based on the ranges of cosmopolitan benthic foraminiferal species, and (or) reliable local or regional species for which ranges can be documented with planktic microfossils or other chronostratigraphic data (figs. 4.3 and 4.4). The ranges of these species, although subject to local facies control, are relatively consistent, represent discrete intervals of time, and are frequently related to global paleoceanographic events (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986; Berggren and Miller, 1989). Among the paleoceanographic events impacting the Paleogene marine benthic faunas include sea level changes (Haq and others, 1987a,b, 1988; Speijer and Schmitz, 1998), hiatuses and (or) erosional events (Keller and others, 1987; Haq, 1991), and water mass

changes (Thomas, 1990; Kennett and Stott, 1995; Kahn and Aubry, 2004; Cramer and Kent, 2005; Thomas, 2006; Zachos and others, 2006). These changes or events often result in extinctions and subsequent recolonization with many first (FAD) or last (LAD) appearance datums (Ortiz, 1995; Speijer and others, 1997; Culver, 2003; Coxall and others, 2006) (fig. 4.5).

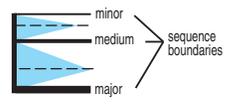
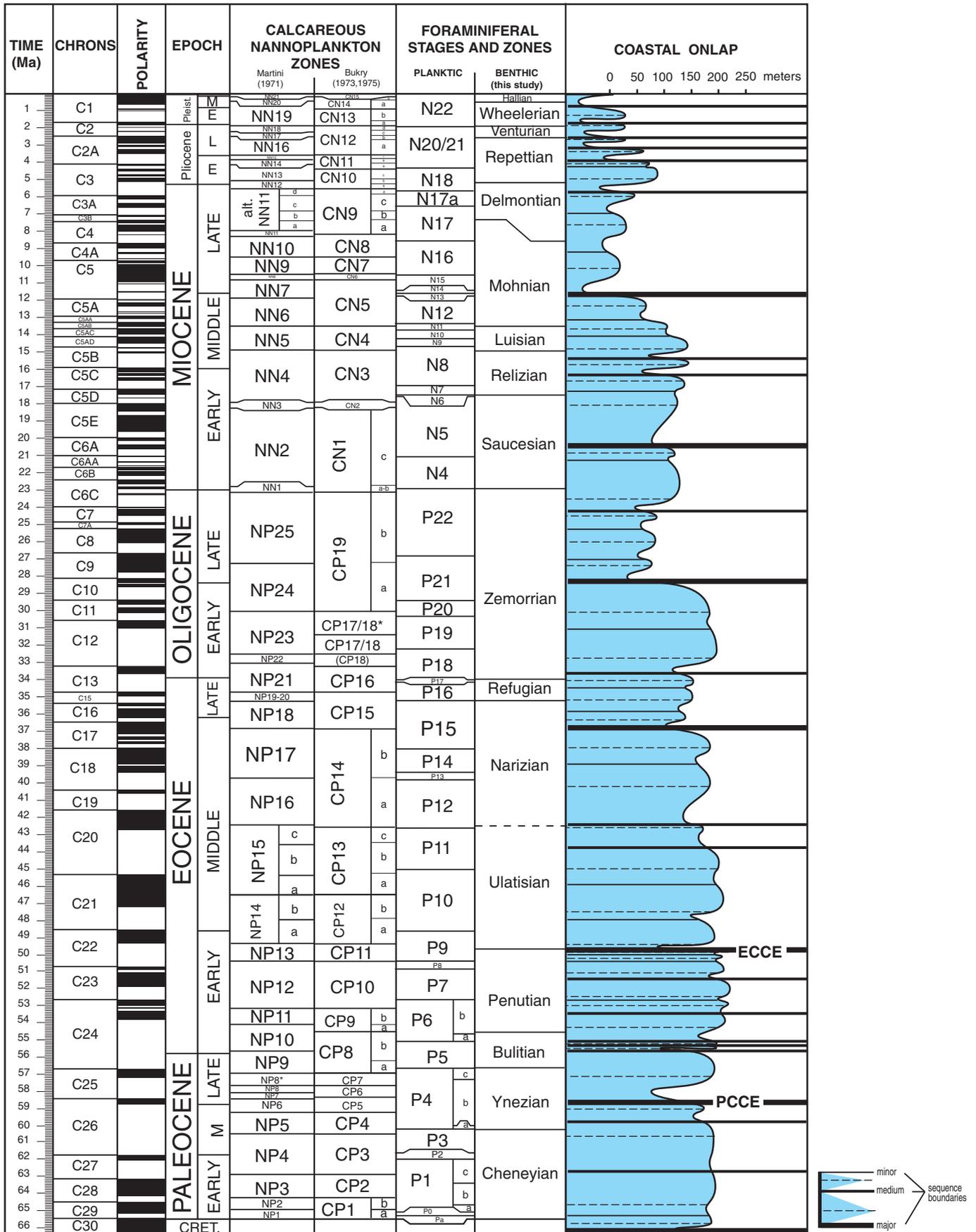
A critical problem previously mentioned by Almgren and others (1988) and not fully addressed at this time is the type sections. Almgren and others (1988) demonstrated that the type sections are not well located, not continuous, and not adequately described either faunally or lithologically. The stage and the interval of time it represents are defined by a type section (stratotype) that “should be a single continuously exposed section in facies favorable for time correlation” (Hedberg, 1976, p. 71). However, because continuous stratotypes are difficult to find the stages are more easily defined by their boundaries (boundary stratotype). These boundaries should be within a continuous sequence and associated with a distinct marker horizon that when recognized away from the stratotype represents an isochronous horizon. Biostratigraphic units (zones) that are defined by their fossils are useful for recognizing stage boundaries. The diagnostic fossils must be widely recognized and have distinct isochronous ranges. The complexity of both the California sections and ecologic conditions has made this an almost impossible task, as the boundaries between the stages are almost always an unconformity or a sparsely fossiliferous interval.

## Critical Sections of the California Paleogene

Five outcrop sections and two wells were designated as the type sections for the California Paleogene Stages and zones (Schenck and Kleinpell, 1936; Goudkoff, 1945; Mallory, 1959; Tipton, 1980) (table 4.1 and fig. 4.6). Many sections have undergone multiple analyses and additional data exist on the microfossil content as well as other chronostratigraphic and sedimentary information. Problems encountered during the subsequent work on these sections is summarized by Almgren and others (1988) and include the inability to locate the sections or diagnostic sedimentary features (formations or units) within the sections, missing sample locations, placement of a stage boundary at the limits of the exposure, unrecognized breaks in the sections, and inadequate descriptions of the faunas and lithologies. The most critical problem with the type sections is that often the benthic foraminiferal faunas do not reflect the original age, stage, or zone interpretation.

The sections are reviewed in order from oldest to youngest—Jergins Cheney Ranch Well No. 1 (type for the Cheneyian Stage), lower Arroyo el Bulito section (type for the Ynezian and Bulitian Stages), Media Agua Creek section (type section

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for the Penutian Stage, and the Ynezian, Bulitian, Penutian and Ulatisian zones), Vaca Valley section (Ulatisian Stage), Devils Den section (Narizian Stage), and the upper Arroyo el Bulito section and Seaboard Welch Well #1 (type section for the Refugian Stage). In addition the Simi Valley and Pacheco Syncline sections are examined because they were considered important by Mallory (1959) and provide additional information on the stages and zones. Reexamination of the benthic foraminiferal faunas includes a taxonomic review and identification of cosmopolitan species. Ages indicated by the benthic foraminiferal species are expressed by the coeval planktic foraminiferal or calcareous nannoplankton zones.

### Jergins Cheney Ranch Well No. 1

The A zone or Cheneyian Stage was defined by Goudkoff in 1945 and included strata between claystone of the Martinez Formation (above) and typical shale of the Moreno Formation (below) in the Jergins Cheney Ranch Well No. 1 (sec. 29, T14S, R13E; American Petroleum Institute number 04019001900000). These strata were considered to predate the Martinez Formation, which is Paleocene in age. No formal type section was designated for this stage because adequate exposures were not located and the stage was only temporarily named the Cheneyian Stage pending further study (Goudkoff, 1945). Zone A and its two subzones were located in wells in the San Joaquin Valley and Escarpado Canyon along the west side of the San Joaquin Valley. Planktic microfossils from the Cheneyian section were examined by Loeblich and assigned to the *Globorotalia compressa-Globigerinoides daubjergensis* zone (Loeblich and Tappan, 1957; Loeblich, 1958), which is equivalent to the P1 zone (Berggren and others, 1995). Hornaday (1974) discusses problems related to the recognition of the Cheneyian Stage and the Danian Stage in California. General consensus among Californian geologists is to group the Cheneyian Stage with the Cretaceous.

Only selected species were published for the Cheneyian Stage (Goudkoff, 1945) (table 4.2). Diagnostic benthic foraminifers include a number of cosmopolitan forms that are common throughout the late Cretaceous and Paleocene (*Coryphostoma midwayensis*, *Gyroidinoides globosus*, and *Neoflabellina jarvisi*). Other diagnostic species listed by Goudkoff

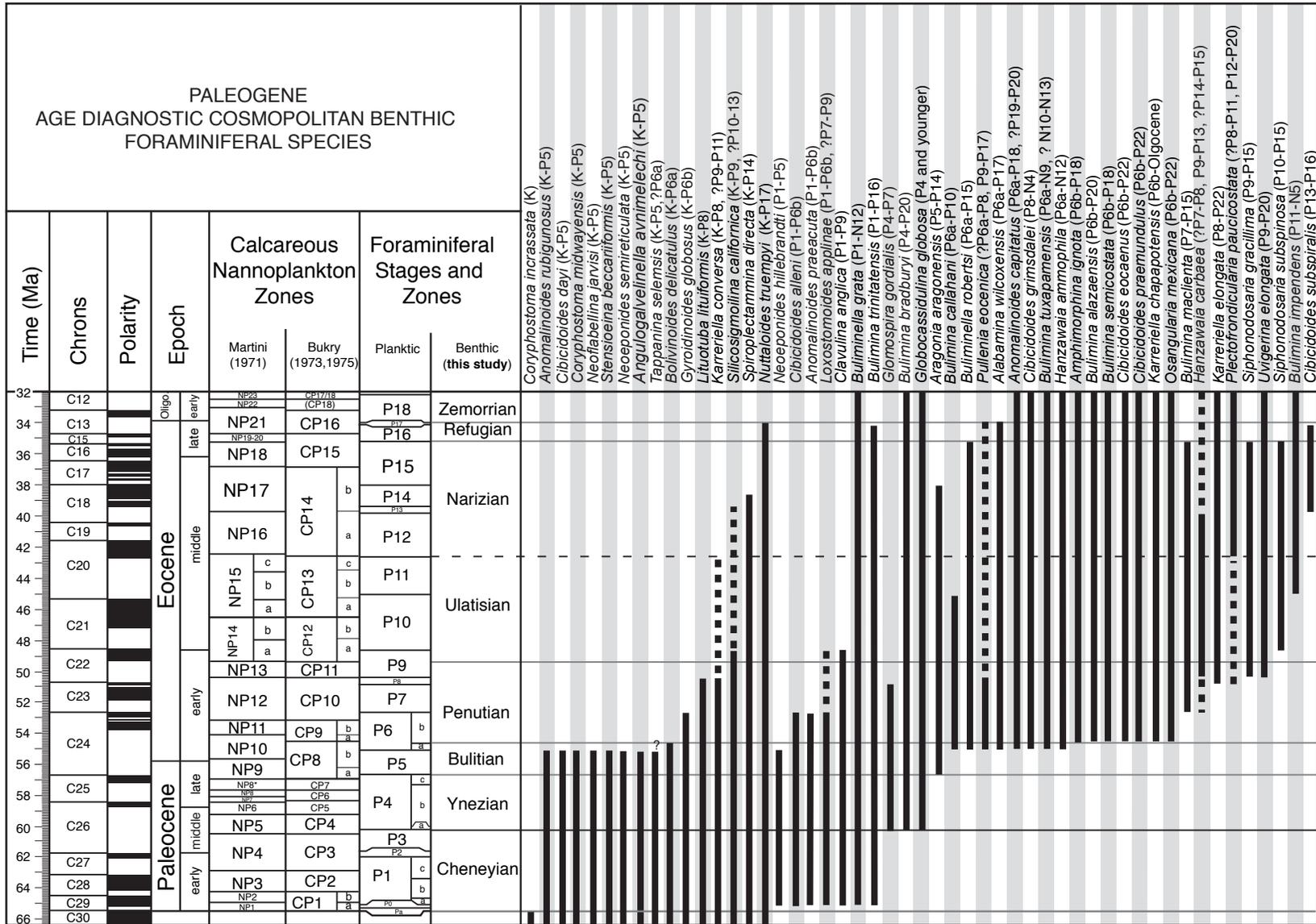
(1945) need further taxonomic work but are probably the species *Anomalinoides rubiginosus*, *Bulimina velascoensis*, *Cibicidoides dayi*, *C. hyphalus*, *Neoeponides hillebrandti*, and *Spiroplectammina richardi*, which restrict this stage to the Paleocene coeval with planktic foraminiferal zones P1 through P5.

### Lower Arroyo el Bulito Section

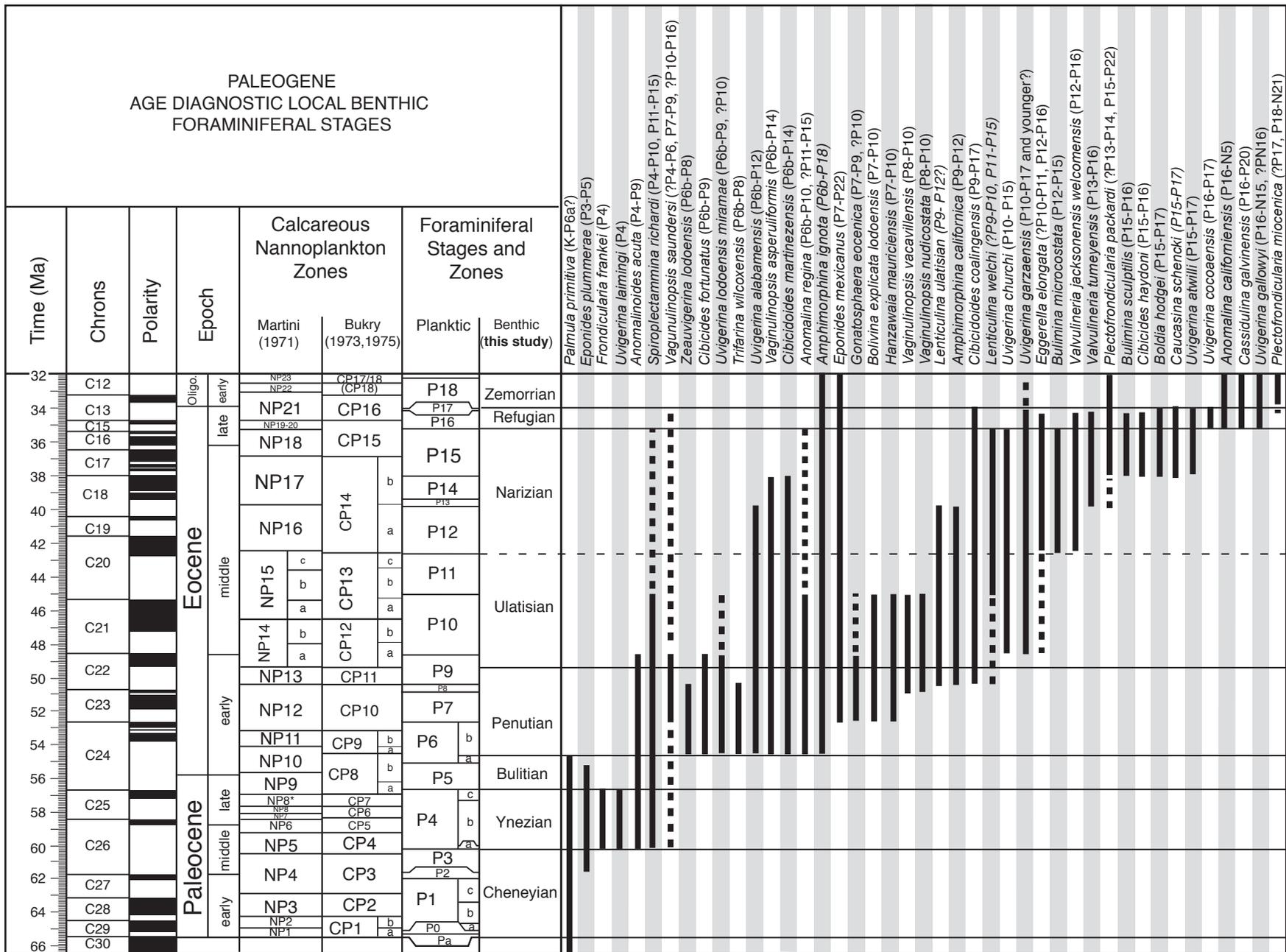
In Arroyo el Bulito, near Santa Barbara, the Anita shale of Kelley (1943; hereafter referred to as Anita shale) conformably overlies the Cretaceous Jalama Formation and is in turn conformably overlain by the Matilija Sandstone. Mallory (1959) designated the interval from the base of the Anita shale to 140 feet below the Sierra Blanca limestone of Vedder (1972; hereafter referred to as Sierra Blanca limestone) as the type section of the Ynezian Stage. The type Bulitian Stage overlies the Ynezian and includes “the Anita shale superjacent to the strata of the topmost Ynezian and subjacent to the 20 feet of siltstone immediately underlying the Sierra Blanca limestone” (Mallory, 1959, p. 29). Almgren and others (1988) were unable to locate the Sierra Blanca limestone in the Arroyo el Bulito section either on current maps of the area (Dibblee, 1950) or by field checking, thus the physical location of the stage type section is in question.

The first benthic foraminiferal study of the Arroyo el Bulito section was the graduate work of Herlyn (1958), which was subsequently published by Mallory and others (1998). Herlyn (1958) recognized Ynezian, Bulitian, Penutian, and Ulatisian benthic foraminifers, but in the later publication the Ynezian Stage is renamed the Hokanian Stage without explanation. In another study, Gibson (1976) provided both planktic and benthic foraminiferal analysis of the Arroyo el Bulito section and several nearby sections. Gibson (1976) recognized an undifferentiated Ynezian/Bulitian interval, a barren interval, and the Penutian Stage. His Ynezian/Bulitian interval contains planktic foraminifers diagnostic of zones P1 through P3, as well as P4. Gibson’s Penutian Stage contains planktic foraminifers that are diagnostic of zones P4 and P5. A third study of the section by Poore (1976) focused on calcareous nannoplankton and planktic foraminifers.

← **Figure 4.2.** California Cenozoic biostratigraphic framework. The international time scale shown here is from Gradstein and others (2004) and Gradstein and Ogg (2005). It is correlated with the paleomagnetic chrons (Berggren, 1972; Berggren and others, 1985; Aubry and others, 1988; Berggren and others, 1995); calcareous nannofossil zones of Bukry (1973, 1975), Okada and Bukry (1980), and Martini (1970, 1971); planktic foraminiferal zones of Blow (1969, 1979), Berggren and Miller (1989), and Berggren (1972); California benthic foraminiferal zonations as proposed in this study and derived from the work of Schenck and Kleinpell (1936), Laiming (1940), Goudkoff (1945), Loeblich (1958), Natland (1952), Wissler (1943, 1958), Kleinpell (1938), Mallory (1959), McDougall (1980, 1988, 1989, 1991, 1993), Almgren and others (1988), Blake (1991), Bartow (1992), and Sliter and others (1993); and the coastal onlap fluctuations of Haq and others (1987a,b, 1988) modified by Johnson and others (2005). Lines on coastal onlap curve indicate sequence boundaries—heavy solid lines are major sequence boundaries, moderate solid lines are medium sequence boundaries, and thin solid lines are minor sequence boundaries. Dashed lines indicate maximum coastal onlap. Pleist., Pleistocene; M, Middle; E, Early; ECCE, Eocene Canyon Cutting Event; PCCE, Paleocene Canyon Cutting Event.

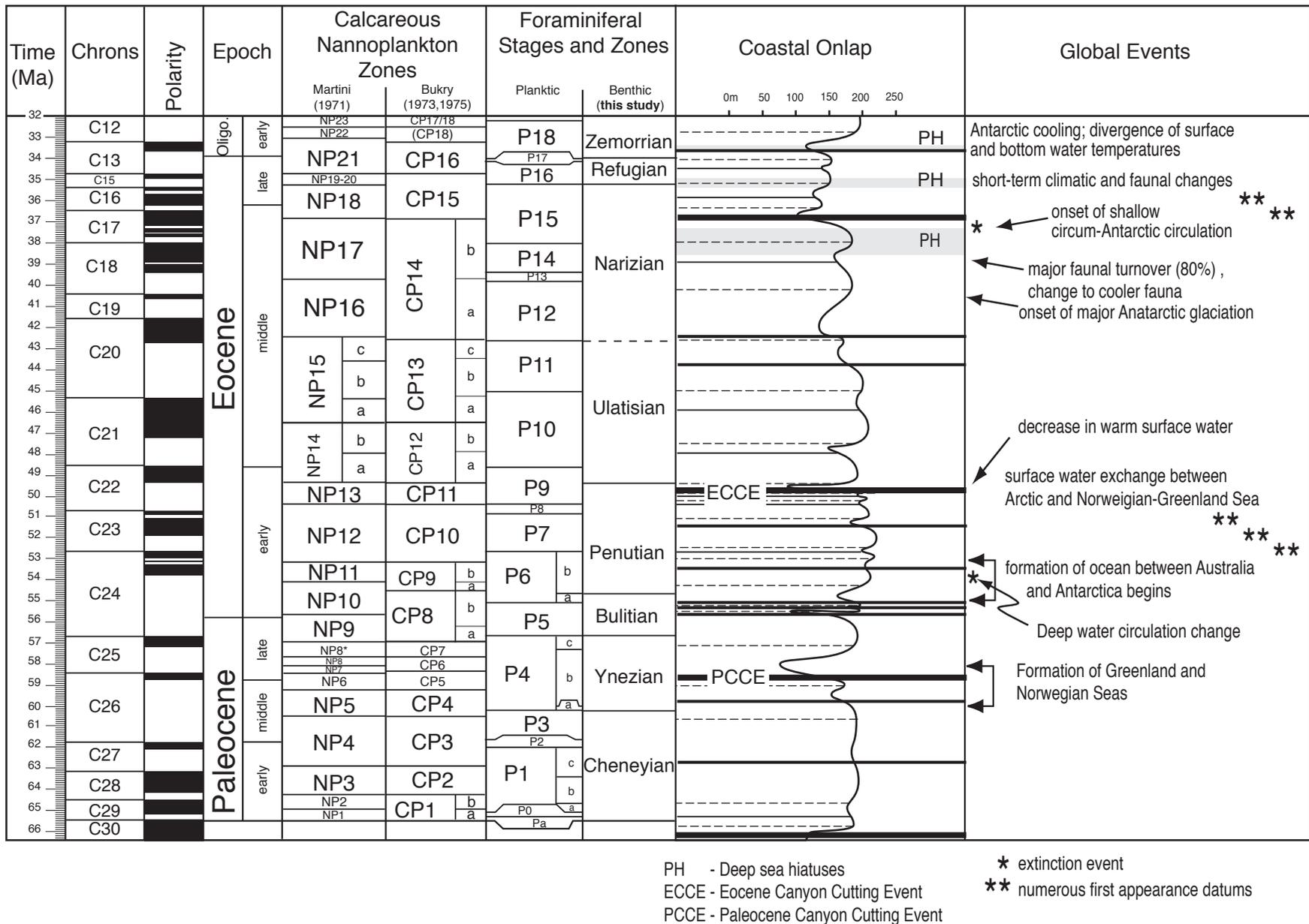


**Figure 4.3.** Ranges of Paleogene age diagnostic cosmopolitan benthic foraminifers. The ranges of cosmopolitan benthic foraminiferal species are plotted against the time scale shown in figure 4.2. The ranges of the species are compiled from various literature sources, such as Tjalsma and Lohmann (1983), van Morkhoven and others (1986), and Berggren and Miller (1989). Oligo., Oligocene.



Critical Sections of the California Paleogene

**Figure 4.4.** Ranges of local and regional Paleogene age diagnostic benthic foraminifers. Ranges of the key species are compiled from various sections throughout California (see appendix 4.1). Oligo., Oligocene.



**Figure 4.5.** Major paleoceanographic events in the Paleogene. Marine faunas were affected by several major oceanographic events correlated with the international time scale and the proposed correlation of the California Paleogene Stages (see fig. 4.2). Oceanographic events shown here include the coastal onlap curve of Haq and others (1987a,b, 1988), as modified by Johnson and others (2005); major extinction, colonization, and appearance events (Berggren and Miller, 1989); deep sea hiatus and canyon cutting events (Keller and others, 1987; Haq, 1991); and tectonic, circulation, and water mass changes (Keller and others, 1987; Kennett and Stott, 1995). Oligo., Oligocene.

**Table 4.1.** Paleogene benthic foraminiferal stages, zones, and type areas.  
[Fm., Formation; Mbr., Member]

| Age                                | Stage  | Type area  | Zone  | Type area   |
|------------------------------------|--|--|---|---|
| Eocene                             | <b>Refugian</b><br>(Schenck and Kleinpell, 1936; Cushman and Simonson, 1944) | Gaviota Fm., Cañada de Santa Anita   | <i>Uvigerina vicksburgensis</i>   | "Leda zone" in the Seaboard Welch Well #1 (sec.10, T16S, R13E)  |
|                                    |  |  | <i>Valvulineria tumeyensis</i> Zone with the <i>Cibicides haydoni</i> and <i>Uvigerina atwilli</i> subzones | upper Sacate Fm. and Gaviota Fm., Arroyo El Bulito  |
|                                    | <b>Narizian</b><br>(Mallory, 1959)   | Point of Rocks Sandstone Member, Kreyenhagen Fm., Devils Den   | <i>Amphimorphina jenkinsi</i>   | Welcome Shale Mbr., Kreyenhagen Fm., Devils Den, Kern County  |
|                                    |  |  | <i>Bulimina corrugata</i>   | Tejon Fm., Point of Rocks Sandstone Mbr. and lower Welcome Shale Mbr., Kreyenhagen Fm., Devils Den, Kern County |
|                                    | <b>Ulatisian</b><br>(Mallory, 1959)  | Vacaville Shale, Dunn's Peak Sandstone, Solano County  | <i>Amphimorphina californica</i>  | Lodo Fm., Media Agua Creek  |
|                                    |  |  | <i>Vaginulinopsis mexicana</i>  | Lodo Fm., Media Agua Creek  |
| <b>Penutian</b><br>(Mallory, 1959) | Lodo Fm., Media Agua Creek   | <i>Alabamina wilcoxensis</i>   | Lodo Fm., Media Agua Creek  |   |
|                                    |  | <i>Plectofrondicularia kerni</i>   | Lodo Fm., Media Agua Creek  |   |
| Paleocene/<br>Eocene               | <b>Bulitian</b><br>(Mallory, 1959)   | Anita Fm., Arroyo El Bulito  | <i>Valvulineria wilcoxensis</i>   | Lodo Fm., Media Agua Creek  |
|                                    |  |  | <i>Bulimina bradburyi</i>   | Lodo Fm., Media Agua Creek  |
| Paleocene                          | <b>Ynezian</b><br>(Mallory, 1959)  | lower Anita Fm., Arroyo El Bulito  | <i>Bulimina excavata</i>  | Lodo Fm., Media Agua Creek  |
|                                    |  |  | <i>Silicosigmoilina californica</i>   | Lodo Fm., Media Agua Creek  |
|                                    | <b>Cheneyian</b><br>(Goudkoff, 1945; Loeblich, 1958)                         | beds between claystone of the Martinez Fm. and typical shale of the Moreno Fm., Jergins Oil Company, Cheney Ranch Well No. 1 (sec. 29, T14S, R13E) | A zone  | Jergins Oil Company, Cheney Ranch Well No. 1 (sec. 29, T14S, R13E)  |

Age interpretations based on calcareous nannoplankton are slightly different from that proposed by Gibson (1976), and in general Poore (1976) considered the section younger than Gibson (1976) (fig. 4.7).

Evaluation of the extensive benthic foraminiferal fauna in the Arroyo el Bulito section is difficult. Attempts to update the taxonomy through a literature study were not adequate because numerous species are labeled as “similar” (cf.) or “with affinities to” (aff.). Further, a wide variety of species names are used. From the base of the Anita shale to sample A8937, a dominantly arenaceous fauna with only long-ranging cosmopolitan species such as *Silicosigmoilina californica* is present (fig. 4.7). Between samples A8937 and A8930 (fig. 4.7), several cosmopolitan species appear such as *Aragonia aragonensis*, *Bolivinoides delicatulus*, *Bulimina bradburyi*, *Coryphostoma midwayensis*, *Nuttalinella florealis*, and *Nuttaloides truempyi*. The FAD of these species is either in the

Cretaceous or in planktic zone P4, and their LAD is either in planktic zone P5 or in the Eocene. These species continue up to samples A8944 through A8954 of Herlyn (1958) and 38 through 31A (fig. 4.7) of Gibson (1976) where species with LAD’s in planktic zone P5 or P6 disappear. In samples A8946 of Herlyn (1958) and higher, new species (*Bulimina alazaensis*, *Bulimina macilenta*, and *Hanzawaia caribaea*) appear whose FAD is in planktic foraminiferal zone P7 or younger, indicating an early Eocene age. Although Herlyn (1958) and Mallory and others (1998) indicated that the upper part of their Anita shale is assigned to the Ulatisian Stage, middle Eocene, there are no species supporting a middle Eocene age.

There is very little agreement among the microfossil groups about the age of this section. Taxonomic problems with the benthic foraminifers do not explain the age discrepancies between the planktic microfossil groups. Further work is needed on this section.

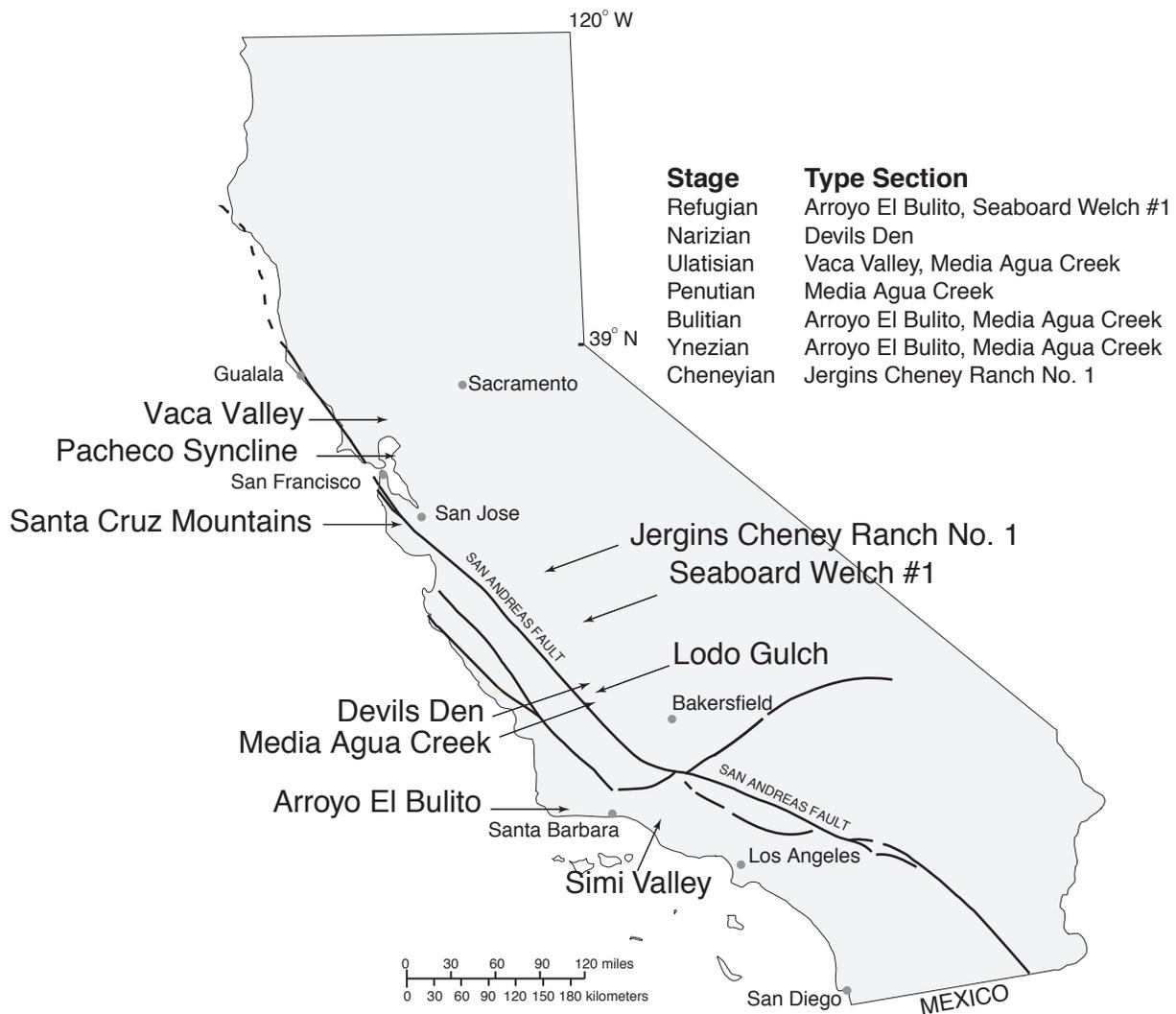


Figure 4.6. Map showing general location of California Paleogene type sections.

**Table 4.2.** Species diagnostic of the Cheneyian Stage according to Goudkoff (1945).  
 [Taxonomic nomenclature was updated. o = characteristic occurrence; x = occasional occurrence]

| Diagnostic species   | Updated taxonomy   | Cosmopolitan range | Zones |      |
|--|--|--------------------|-------|------|
|  |  |                    | A-2   | A'-2 |
| <i>Bolivina incrassata</i> Reuss   | <i>Coryphostoma incrassata</i> or <i>C. midwayensis</i>      | K or K-P5          | x     |      |
| <i>Bulimina petroleana</i> Cushman and Hedberg                             | probably <i>B. velascoensis</i>                              | P1-P5              | x     | x    |
| <i>Bulimina</i> cf. <i>B. triangularis</i> Cushman and Parker              | <i>Pyramidina triangularis</i>                               | K - ?              | o     | o    |
| <i>Cibicides</i> cf. <i>C. ungeriana</i> (d'Orbigny)                       | probably <i>Cibicoides dayi</i>                              | K-P5               | o     |      |
| <i>Epistomina caracolla</i> (Roemer)                                       | probably <i>Neoeponides hillebrandti</i> or <i>N. lunata</i> | P1-P5              | x     | x    |
| <i>Flabellina pilulifera</i> Cushman and Campbell                          | <i>Neoflabellina jarvisi</i>                                 | K-P5               | x     |      |
| <i>Globulina lacrima subsperica</i> Cushman and Goudkoff                   |  | long ranging       | x     |      |
| <i>Gyroidina globosus</i> (Hagenow)  | <i>Gyroidinoides globosus</i>                                | K-P6a              | x     | x    |
| <i>Robulus</i> sp.   | No description or figure                                     | ?                  | o     | o    |
| <i>Spiroplectoides clotho</i> (Gryzbowski)                                 | probably <i>Spiroplectamina richardi</i>                     | P4-P14             | o     |      |
| <i>Vaginulina</i> ( <i>Marginulina</i> ) cf. <i>V. plummerae</i> (Cushman) |  | ?                  | o     |      |
| <i>Valvulinera lillisi</i> Cushman and Goudkoff                            | <i>Anomalinoides rubiginosis</i>                             | K-P5               | o     |      |
| <i>Valvulinera orolomaensis</i> Cushman and Goudkoff                       | probably <i>Cibicoides hyphalus</i>                          | K-P5               | x     | o    |
| <i>Dentalina megapolitana</i> Reuss  |  | ?                  |       | x    |

## Media Agua Creek Section

The Media Agua Creek section, located along the west side of the San Joaquin Valley (fig. 4.6), is key to the California Paleogene biostratigraphy as many of the type stages and (or) zones occur in this section. In Media Agua Creek, the Lodo Formation conformably overlies the Cretaceous rocks of English (1921) and is in turn unconformably overlain by the Point of Rocks Sandstone Member of the Kreyenhagen Formation. The absence of the Cheneyian Stage was attributed to the coarseness of the sediment (Mallory, 1970). Planktic microfossil studies (Poore, 1976, 1980; Warren, 1983; Almgren and others, 1988) determined that the Media Agua Creek section was not continuous, with unconformities occurring at the base and within the lower Lodo Formation, removing all but a small portion of the Paleocene P4 planktic foraminiferal zone. The early Eocene planktic foraminiferal zones P6b through P10 and calcareous nannoplankton zones CP9 through CP13 were recognized in the upper Lodo Formation and in the Point of Rocks Sandstone Member of the Kreyenhagen Formation. Planktic microfossils are not preserved in the upper part of the section, so no age assignments were possible for samples A7027 through A7007 (Poore, 1976) (fig. 4.8). Paleomagnetic analysis of the upper Lodo Formation and the Point of Rocks Sandstone Member of the Kreyenhagen Formation indicates the presence of early and middle Eocene Chrons C22r through C20r (Prothero, 2001a). Thus, planktic microfossil and paleomagnetic interpretations are in general agreement.

A reexamination of the Media Agua Creek benthic foraminiferal faunas and an updated taxonomy suggests that this section includes a short Paleocene interval that is overlain by the lowermost Eocene strata. If the late middle Eocene is present, it cannot be recognized in Mallory's (1959, 1970) samples. Updating the taxonomy involved only a literature examination and the assumption that the name originally given to the specimen was correct. Additional work is needed to verify the original designation and the consistency of the identification.

The lower Lodo Formation in the Media Agua Creek section (lower Ynezian of Mallory, 1959, 1970) contains primarily arenaceous species and a few cosmopolitan species. These species either originate in the Cretaceous and range into the Eocene or first appear in the late Paleocene (planktic zone P4) (fig. 4.8). Sample A7079 (fig. 4.8), which overlies the dominantly arenaceous late Paleocene, is a mixture of Paleocene and Eocene microfossils. Cosmopolitan species in this assemblage suggest an early Eocene age, coeval with planktic foraminiferal zone P6b or younger. Cosmopolitan species appearing in samples A7078 through A7037 (fig. 4.8) are early Eocene in age and include benthic foraminiferal species that first appear in planktic foraminiferal zone P6b or P7 and last appear in P8 or P9.

With the exception of the local species, no new age diagnostic species appear above sample A7037 (fig. 4.8). The microfauna is uniform and unchanging, containing species that

first appear in the early Eocene and last appear in the middle or late Eocene. Ranges of local species (*Uvigerina garzaensis*, *Eggerella elongata*, *Lenticulina ulatisianensis*, and *L. welchi*) suggest that the upper portion of the section is middle Eocene, coeval with planktic zones P9 through P12. No late middle or late Eocene assemblages are recognized in the sampled interval (fig. 4.8).

Based primarily on cosmopolitan species, the Media Agua Creek section is interpreted as containing an unconformity-bounded Paleocene and lower through middle Eocene strata. The Paleocene interval is coeval with planktic zone P4 and calcareous nannoplankton zone CP7 and was previously considered part of Mallory's Ynezian Stage. The Paleocene interval is unconformably overlain by an early Eocene interval coeval with planktic microfossil zones P6b through P9 and CP9 through CP12. This early Eocene interval was previously considered part of Mallory's Ynezian, Bultian, Penutian, and Ulatisian Stages but is now assigned to the Penutian Stage. The early Eocene is overlain by middle Eocene strata coeval with planktic zones P9 through P10 and CP12 through CP13. The upper part of the section is probably middle Eocene based on the presence of Chron C20 (Prothero, 2001a). The middle Eocene strata are assigned to the Ulatisian Stage. This reevaluation, like the planktic microfossil analysis, diverges from the long established belief that the Media Agua Creek section represents continuous deposition from the early Paleocene through the late Eocene. This revised benthic foraminiferal age interpretation agrees closely with the planktic microfossil and the paleomagnetic age interpretations, which also find the section to be discontinuous and not as young as originally assumed.

## Vaca Valley Section

The type section of the Ulatisian Stage is the "Vacaville Shale in the vicinity of Dunn's Peak along Ulatis Creek in the Vaca Valley Quadrangle" (Mallory, 1959) (fig. 4.9). This section was originally described and mapped by Boyd (1949, 1998). The type section of the Ulatisian Stage includes the Vacaville Shale below the dark gray silty mudstone member of Boyd (1949) to the base of Boyd's foraminiferal section (Mallory, 1959, p. 40). Almgren and others (1988) noted problems with the placement of the Ulatisian boundaries and the relationship of the stage to adjacent stages. Specifically, Almgren and others (1988) noted that the upper Ulatisian Stage at Ulatis Creek (Vaca Valley section) is younger than the upper Ulatisian zones in the Media Agua Creek section (type section for the zones) and that the base of the stage in the type section is older than the base of the lower Ulatisian zone at its type locality.

Mallory (1959) based his Ulatisian Stage on Boyd's work (1949, 1998) in Vaca Valley. This section was reexamined by Vaughan (1976), who concluded that only the upper zone of the Ulatisian Stage was present in Vaca Valley and that the

upper part of the section also contained species diagnostic of the lower Narizian Stage. Thus, Vaughan (1976) considered this section to be undifferentiated Ulatisian/Narizian Stages. Because of this confusion, Vaughan (1976) used the Laiming foraminiferal zones to interpret the age of the foraminiferal assemblages (fig. 4.9). Vaughan (1976) also examined the planktic microfossils from the type Ulatisian section and concluded that the section included planktic foraminifers diagnostic of zones P9 through P12 and calcareous nannoplankton diagnostic of zones CP11 through CP13. Paleomagnetic analysis of the Vaca Valley section recognized magnetic Chrons 22r through C20r (Prothero, 2001a; Prothero and Brabb, 2001) (fig. 4.9). There are no microfossil assemblages from the interval interpreted as Chron 20r. The age interpretations proposed by the planktic microfossils and paleomagnetism are similar.

The few cosmopolitan benthic foraminiferal species present in the Vaca Valley section between the base of the section (sample A4781A) and the glauconitic sandstone (samples 34aVS through 8Vs) indicate that this interval is middle Eocene through Oligocene in age (P9 to P22; fig. 4.9). These species continue above the glauconitic sand and are joined by *Bulimina semicostata*, *Buliminella robersti*, *Nuttaloides truempyi*, and *Pullenia eocenica*, which limit the age of this upper interval to the middle Eocene, coeval with planktic zones P10 through P15. Local species with known ranges suggest that the section below the glauconitic sandstone is middle Eocene, coeval with planktic zones P9 through P10 based on the presence of several species of *Vaginulinopsis* and *Trifarina wilcoxensis*, whereas the upper interval, which contains rare to few specimens of *Uvigerina garzaensis*, *Valvulineria jacksonensis welcomensis*, and *Boldia hodgei*, is middle Eocene, coeval with planktic zones P12 through P15. This revised interpretation of the benthic foraminifers in the Vaca Valley section suggests the section is middle Eocene in age and should be assigned to the Ulatisian Stage. The middle Eocene age interpretation is supported by the planktic microfossil and paleomagnetic interpretations (fig. 4.9). Because the upper and lower boundaries of the Ulatisian Stage are not present in the Vaca Valley section, a new type section is needed.

## Devils Den Section

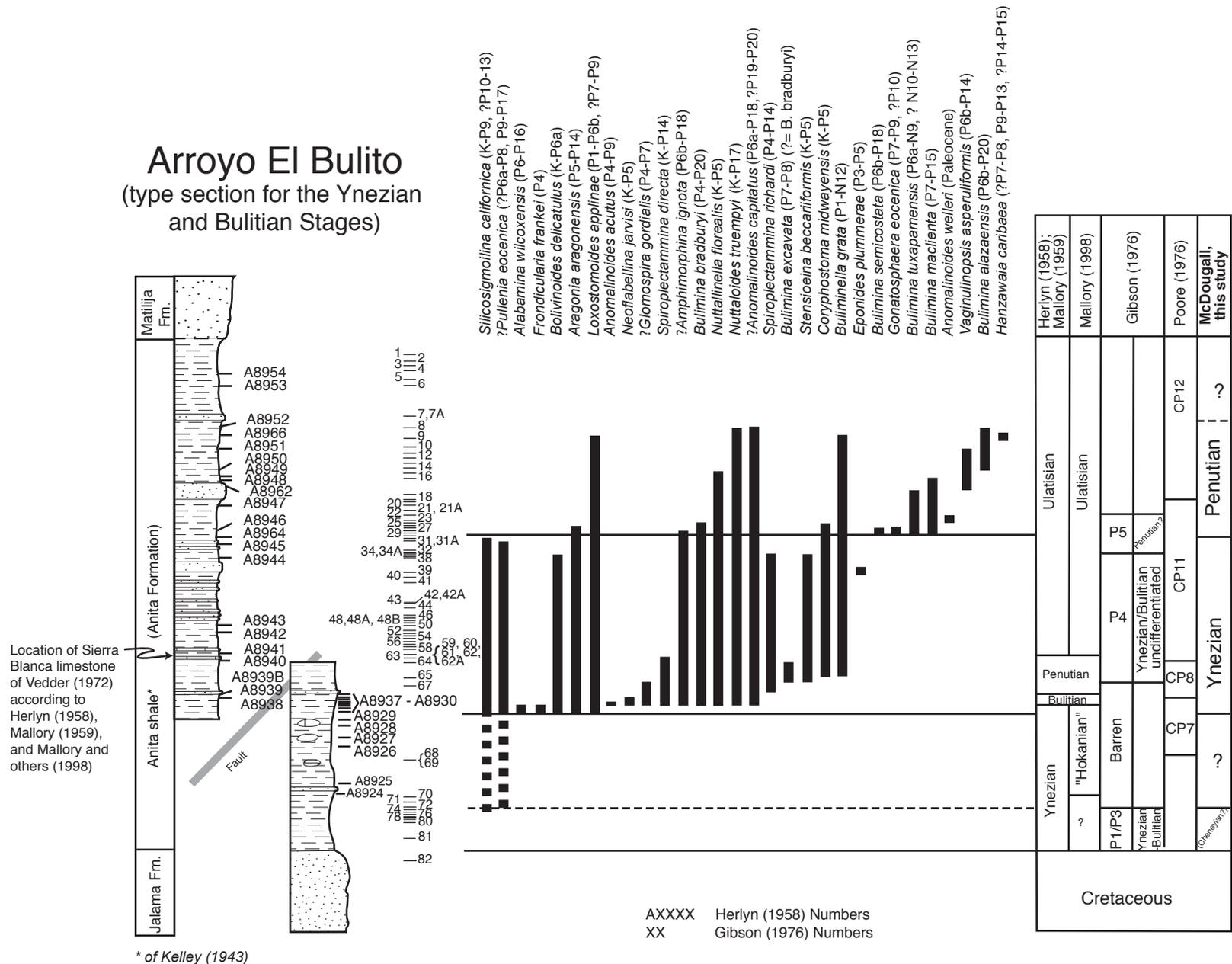
Mallory (1959) designated the Point of Rocks Sandstone and lower Welcome Shale Members of the Kreyenhagen Formation in the Devils Den area as the type section of the Narizian Stage and zones (*Bulimina corrugata* and *Amphimorphina jenkinsi* zones). The type section is the stratigraphic interval from "typical Point of Rocks Sandstone with the possible exception of the basal 75 feet, plus the Welcome Member of the Kreyenhagen Formation to a point just below the superjacent Wagonwheel Formation" (Mallory, 1959, p. 55). Almgren and others (1988) noted that the section is not continuous and that there is an unconformity between

the Kreyenhagen Formation and the overlying Wagonwheel Formation that removes the late Narizian and possibly some of the early Narizian strata from this section.

Benthic foraminiferal assemblages from the Devils Den section were discussed by Mallory (1959), Kleinpell and Mallory (1998), and Smith (1956) (fig. 4.10). They place the base of the Narizian Stage at 215 meters above the Point of Rocks Sandstone Member and the top of this stage below sample 83 in the Welcome Shale Member of the Kreyenhagen Formation (Kleinpell and Mallory, 1998). Subsequent work by Almgren and others (1988) placed the entire section in the late Eocene A zones of Laiming (1940) but considered the section to be no younger than middle Eocene, coeval with calcareous nannoplankton zones CP12 through CP14. This interpretation was based on samples A7133 through A7138 from the basal Point of Rocks Sandstone Member of the Kreyenhagen Formation in the Devils Den section (Mallory, 1959; Kleinpell and Mallory, 1998) (fig. 4.10) and sample 74CB1291A, also from the basal Point of Rocks Sandstone but in the nearby aqueduct section (Berggren and Aubert, 1983; Warren, 1983). These samples contain calcareous nannoplankton diagnostic of zone CP13 and planktic foraminifers diagnostic of zone P10. Barren or only sparsely fossiliferous samples in the upper Welcome Shale Member suggest an undifferentiated middle to late Eocene age (Almgren and others, 1988). The basal Point of Rocks Sandstone Member contains no distinctive Narizian benthic foraminifers and was therefore interpreted as Ulatisian in age (Mallory, 1959; Berggren and Aubert, 1983; Kleinpell and Mallory, 1998).

Paleomagnetic analysis of the Devils Den section by Prothero (2001a) indicates that Chrons C20n or C21n and C19n or C20n are present in the Point of Rocks Sandstone and Welcome Shale Members of the Kreyenhagen Formation, respectively. This interpretation places both formations in the middle Eocene. Late Eocene Chrons C15r and C15n are recognized in the overlying Wagonwheel Formation (fig. 4.10).

Age diagnostic cosmopolitan benthic foraminifers occurring in the type section include long-ranging species that are not restricted to the middle or late Eocene (fig. 4.10). Only a few local species have ranges that provide any age limits. *Lenticulina welchi*, *Vaginulinopsis asperuliformis*, and *Valvulineria jacksonensis welcomensis* occur in the lower part of the type section and suggest a middle to late Eocene age coeval with planktic zones P12 through P14. The middle and upper part of the section contains *Boldia hodgei*, *Bulimina microcostata*, *Bulimina sculptilis*, *Caucasina schencki*, *Plectofrondicularia packardi* (rare), and *Valvulineria tumeyensis*, which have FAD between planktic foraminiferal zones P13 and P15, indicating this part of the section is late Eocene in age. The overlying Wagonwheel Formation contains only local species whose ranges indicate an age of late Eocene, coeval with planktic foraminiferal zones P16 through P17. The revised age interpretation of the section based on the foraminifers is similar to the paleomagnetic interpretation.



**Figure 4.7.** Biostratigraphy and ranges of diagnostic species in the Arroyo el Bulito section, type section for the Ynezian and Bultitian Stages. Benthic foraminifers from the lower Arroyo el Bulito section were originally described by Herlyn (1958) and subsequently published by Mallory and others (1998). Species names were modified to conform to current taxonomy. Additional benthic foraminiferal and planktic microfossil studies are from Gibson (1976) and Poore (1976). Fm., Formation.

## Upper Arroyo el Bulito Section and Seaboard Welch Well #1

The Refugian Stage was defined by Schenck and Kleinpell (1936) as the strata deposited after the Tejon Formation in the San Joaquin Valley and before strata assigned to the Zemorrian Stage. They designated Cañada Santa de Anita as the type section and listed both benthic foraminifers and mollusks in the description of the stage. Cushman and Simonson (1944) and Kleinpell and Weaver (1963) subsequently defined the two zones included in this stage. Tipton (1980) redefined the Refugian Stage and zones by designating the uppermost Sacate Formation in Arroyo el Bulito as the type section for the early Refugian (fig. 4.11) and the “Leda zone” of Cushman and Simonson (1944) in the Seaboard Welch Well #1 (sec. 10, T16S, R13E; American Petroleum Institute number 04019061290000) as the type section for the late Refugian (fig. 4.12). The upper part of the Alegria Formation contains Zemorrian benthic foraminifers and is now excluded from the Refugian Stage (Almgren and Filewicz, 1984; Prothero and Thompson, 2001). Planktic microfossils in the early Refugian of the Arroyo el Bulito section are assigned to planktic zones P15/P16 undifferentiated and NP19 through NP20 (Warren and Newell, 1980; Prothero and Thompson, 2001). Late Eocene Chrons C15r through C13r are recognized in the Refugian strata in Arroyo el Bulito (Prothero and Thompson, 2001).

Only a few cosmopolitan species are present in the upper Arroyo el Bulito section and Seaboard Welch Well #1. Except for *Alabamina wilcoxensis*, the ranges of these species do not limit the age of this section. *Alabamina wilcoxensis* last appears in the late Eocene planktic foraminiferal zone P16 (figs. 4.11 and 4.12). Local species (*Uvigerina atwilli*, *U. cocoaensis*, and *U. gallowayi*) with shorter ranges limit the section to the late Eocene, coeval with planktic zones P16 through P17.

## Simi Valley Section

The Simi Valley section in southern California was identified by Mallory (1959) as a section that could provide additional data about the Paleocene that the Arroyo el Bulito or Media Agua Creek sections could not. The Simi Valley section was originally examined by University of California graduate students (Browning, 1952; Grier, 1953) and the results published by Mallory (Browning and others, 1998). The section was interpreted as containing faunas diagnostic of the Ynezian, Bulitian, and Penutian Stages and zones (fig. 4.13). A more comprehensive examination of this section occurred in 1983, when in addition to benthic foraminifers (Heitman, 1983; Schymiczek, 1983), planktic foraminifers and calcareous nannoplankton were examined (Filewicz and Hill, 1983). Planktic foraminiferal zones P4 through undifferentiated zones P5 and P6a and calcareous nannoplankton zones CP5 through CP9 (Santa Susana Formation) and CP11 through CP13 (Llajas Formation) were

recognized along with several barren or nondiagnostic intervals (fig. 4.13). The calcareous nannoplankton suggested an unconformity between the Santa Susana and Llajas Formations. The dramatic change in water depth indicated by the benthic foraminifers also suggests the presence of an unconformity between the Santa Susana and Llajas Formations (Schymiczek, 1983). Paleomagnetic studies later confirmed the ages and the unconformity indicated by the planktic microfossils (Bottjer and others, 1991).

Several cosmopolitan species are recognized in the Simi Valley section, but the validity of the taxonomy is questioned because the specimens were never directly examined (fig. 4.13). Cosmopolitan species in the lower Santa Susana Formation include *Angulogavelinella avnimelechi*, *Anomalinoidea acutus*, *Anomalinoidea rubiginosus* (*A. capitatus?*), *Bulimina bradburyi?*, *Cibicidoides alleni* (*C. eocaenicus?*), *Cibicidoides dayi*, *Coryphostoma midwayensis*, *Gyroidina globosus*, and *Palmula primitiva*, which restrict the age of the lower Santa Susana Formation to the late Paleocene, coeval with planktic foraminiferal zone P4. This interval also contains species that typically do not appear until the Eocene. Taxonomic problems are probably the source of this discrepancy. Many of the Paleocene cosmopolitan species last appear between samples A7641 and MVF12 (fig. 4.13). The interval from MVF12 through SS586 contains benthic foraminifers that originate in the Paleocene and continue into the Eocene; none of the species present restrict the age of this assemblage to the Paleocene or Eocene. Planktic microfossils and paleomagnetic data also suggest that this interval spans the Paleocene/Eocene boundary. Local species such as the various species of *Vaginulinopsis* suggest an early Eocene rather than a late Paleocene age.

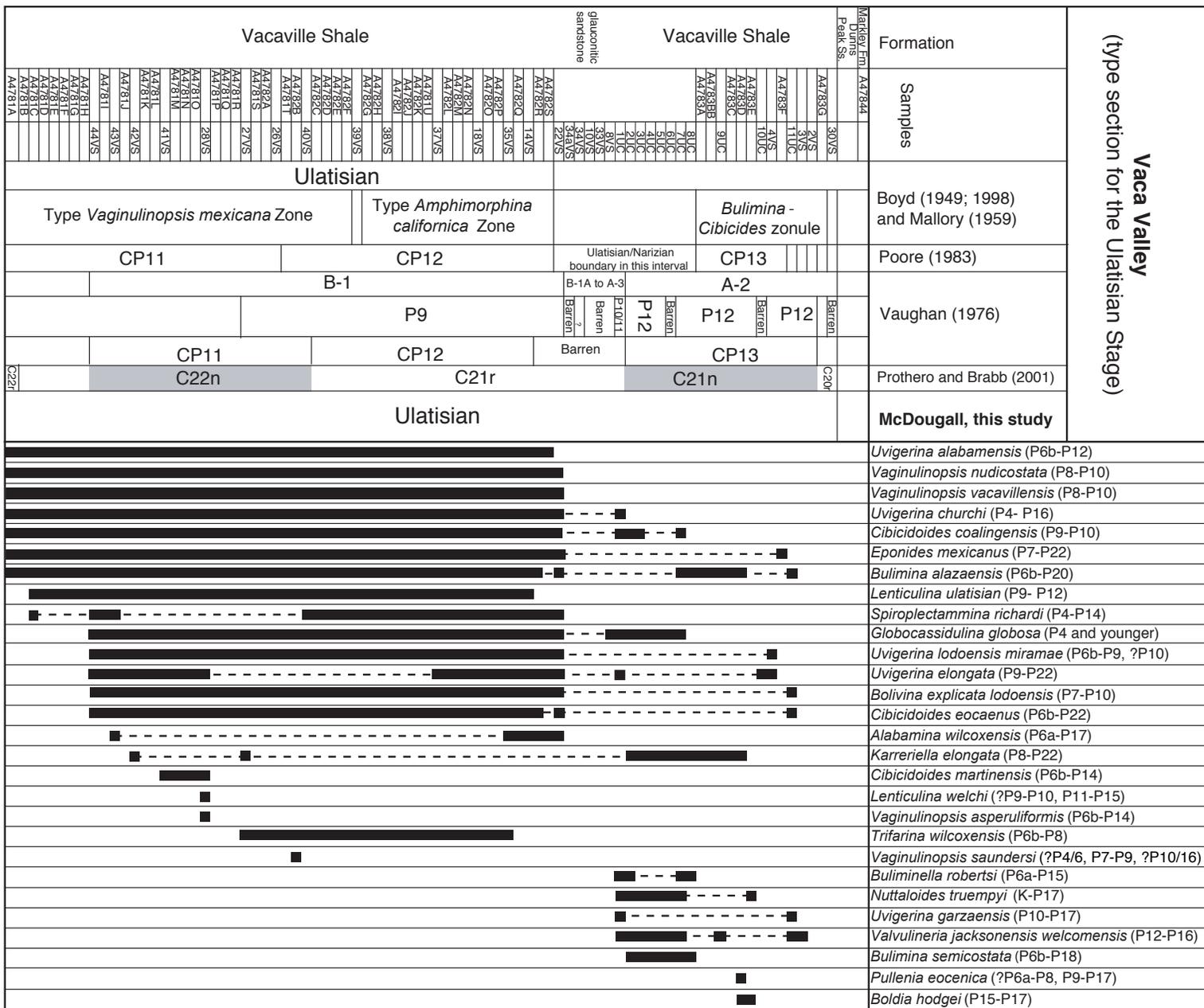
In the upper Santa Susana Formation (samples A7643 through A7656), all Paleocene cosmopolitan species are gone and only species that range from the Paleocene into the early Eocene are present. Again, species of *Vaginulinopsis* suggest this interval is Eocene.

No cosmopolitan species are present in the Llajas Formation. Diagnostic local species include *Cibicidoides coalingsensis*, *Lenticulina welchi*, and several species of *Vaginulinopsis*, which suggest assignment to the middle Eocene, coeval with planktic foraminiferal zones P9 through P11. This interpretation is compatible with the calcareous nannoplankton and the paleomagnetic studies (Filewicz and Hill, 1983; Bottjer and others, 1991).

## Pacheco Valley Section

Mallory (1959) thought the Pacheco Syncline sections added significantly to the knowledge about the Paleogene foraminiferal faunas because of the comprehensive benthic foraminiferal study by Smith (1957). In the Pacheco Syncline, Mallory (1959) and Smith (1957) recognized all the lower Tertiary Stages overlying the Cretaceous (fig. 4.14). Unconformities have subsequently been recognized between the Cretaceous/Tertiary strata, the Vine Hill Sandstone/Las Juntas Shale, and the





**Figure 4.9.** Biostratigraphy and ranges of diagnostic species in the Vaca Valley section, type Ulatisian Stage. Ranges of diagnostic benthic foraminifers from the original study by Boyd (1949, 1998) and the later study by Vaughan (1976) are shown. Planktic microfossil interpretations are by Poore (1976) and Vaughan (1976). Paleomagnetism are from Prothero and Brabb (2001). Ss., Sandstone; Fm., Formation.

Las Juntas Shale/Muir Sandstone (Poore, 1976; Graymer and others, 1994). Calcareous nannoplankton diagnostic of zones CP7, CP10, CP12, and CP13 were recognized in this section by Poore (1976) (fig. 4.15).

A revision of the benthic foraminiferal taxonomy and the addition of several new samples in the Pacheco Syncline sections highlight the presence of many cosmopolitan benthic foraminiferal species (figs. 4.14 and 4.15). The Vine Hill Sandstone is assigned to the Paleocene, coeval with planktic foraminiferal zone P4, based on the appearance of the cosmopolitan species *Anomalinoides rubiginosus*, *Cibicidoides alleni*, *C. dayi*, *Coryphostoma midwayensis*, *Frondicularia frankei*, and *Palmula primitiva* and species that first appear in the Paleocene or Cretaceous, such as *Loxostomoides applinae* and *Silicosigmoilina californica* (fig. 4.14). The faunal assemblage in sample EB599 near the base of the Las Juntas Shale contains the first appearance of several early Eocene cosmopolitan benthic foraminifera (*Bulimina alazaensis*, *B. callahani*, *B. tuxapamensis*, *Buliminella robertsi*, *Cibicidoides praemundulus*, *Plectofrondicularia paucicostata*, and *Pullenia eocenica*) (fig. 4.14). Early Eocene local species that first appear in this sample include *Amphimorphina ignota*, *Gonatosphaera eocenica*, *Trifarina wilcoxensis*, and *Vaginulinopsis asperuliformis*. Many of these Eocene species continue to appear in the Las Juntas Shale, Muir Sandstone, and younger sediments; however, cosmopolitan and local species that last appear in the early Eocene (*Clavulina anglica*, *Glomospira gordialis*, and *Lituotuba lituiformis*) are not seen above sample Mf7770 (fig. 4.14). The benthic foraminiferal fauna in the Alhambra Formation is less diverse and abundant than in the underlying sediments but a number of age diagnostic species first appear in samples A6663 and Mf7773 (fig. 4.14). Cosmopolitan species *Uvigerina elongata* and *Karreriella elongata* and local species *Amphimorphina californica*, *Eggerella elongata*, *Lenticulina ulatisian*, and *Lenticulina welchi* suggest that this formation is middle Eocene, coeval with planktic foraminiferal zones P9 through P12.

## Discussion of the Paleogene Zonation

Comparison of the California Paleogene type Stages and zones with the international time scale demonstrates the time transgressive nature of the stages (fig. 4.16). The overlap of the stages is similar to the overlap observed by previous workers (Poore, 1976, 1980; Almgren and others, 1988). Revised interpretations of the stages, type sections, and the use of cosmopolitan and selected benthic foraminiferal species indicate that the stages identify discreet intervals of time (fig. 4.17). The age of each stage and type section, as well as revisions and areas for further study, are discussed below.

### Cheneyian Stage

The Cheneyian Stage was never adequately defined. Faunal lists were not published and a type section was never

clearly identified. Cheneyian age strata are frequently included with the underlying Cretaceous strata. On the basis of planktic foraminifera, this stage represents strata coeval with planktic foraminiferal zone P1 and probably strata coeval with zones P2 and P3. Globally, the Danian Stage ranges from P1 through P3 and is believed to end at the P3a/P3b boundary, where there is a drop in sea level. At several locations the boundary between the Danian and Selandian Stages marks the change from high dissolved oxygen content and low productivity to low dissolved oxygen content and high productivity in the oceans (Speijer and others, 1997; Speijer and Schmitz, 1998).

Diagnostic species identified by Goukoff (1945) range throughout the Paleocene, except *Coryphostoma incrassata*, *Bulimina velascoensis*, and *Neoeponides hillebrandti*. These species either last appear or first appear at the Cretaceous/Tertiary boundary (figs. 4.3 and 4.4).

### Ynezian Stage

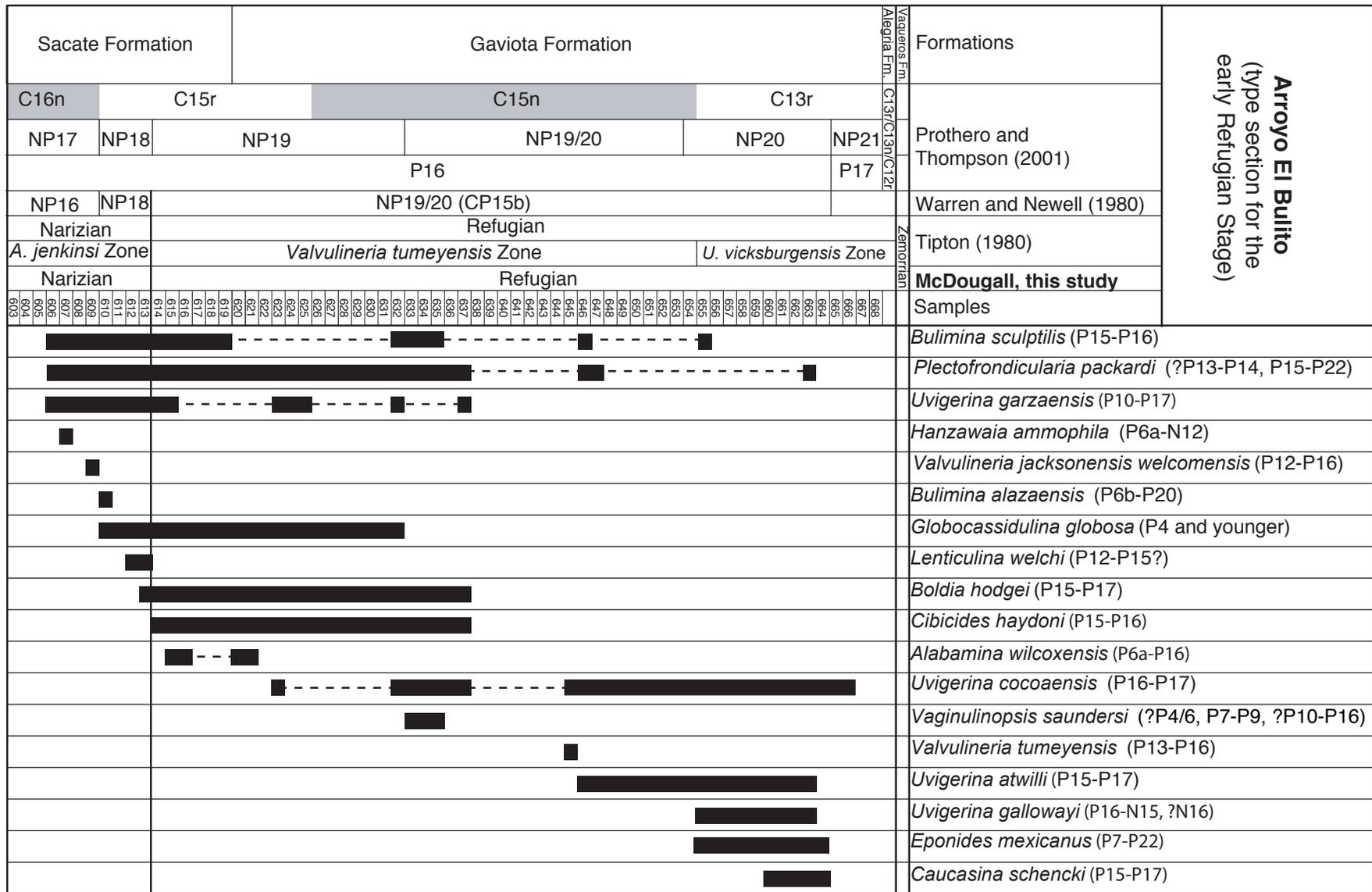
Strata assigned to the Ynezian Stage in this study range in age from P1/P3 undifferentiated through P5 (fig. 4.7). Because of confusion regarding the Cheneyian Stage, Mallory did not recognize Cheneyian Stage or Danian Stage strata overlying the Cretaceous in the Arroyo el Bulito section (type Ynezian Stage). Planktic foraminifera indicated that the interval assigned to zones P1/P3 (undifferentiated) and the overlying sparsely fossiliferous to barren interval (samples A8925 to A8929 and 82 to 70) should be excluded from the Ynezian Stage. The lower boundary of the Ynezian Stage in Arroyo el Bulito is therefore younger than P3 but older than CP7 (late P4). In the Media Agua Creek and Pacheco Syncline sections, the lower boundary is marked by an unconformity that occurs in zone CP7, whereas in the Simi Valley section the lower boundary occurs in zone CP5 or slightly older. The upper boundary in all the sections occurs in zones P4 and CP7, and is an unconformity. Until a new type section or boundary stratotypes are designated for the Ynezian Stage, the exact placement of the stage boundaries is in question. The Ynezian Stage is late Paleocene and appears to be coeval with planktic foraminiferal zone P4 and calcareous nannoplankton zones CP5 through CP7 (fig. 4.2).

Despite the unconformities, a distinctive benthic foraminiferal fauna is associated with the Ynezian Stage. The lower boundary can be recognized by the first appearances of *Anomalinoides acutus*, *Bulimina bradburyi*, *Bulimina excavata*, *Glomospira gordialis*, *Globocassidulina globosa*, and *Spiroplectamina richardi*. *Frondicularia frankei* and *Uvigerina laimingi* are restricted to the Ynezian Stage. The upper boundary of the stage is identified by the first appearances of *Aragonia aragonensis* and *Cibicidoides coalingensis* (figs. 4.3 and 4.4).

### Bulitian Stage

Strata assigned to the Bulitian Stage in this study range in age from P4 through P8 (CP4 through CP10). There is no





**Figure 4.11.** Biostratigraphy and ranges of diagnostic species in the Arroyo el Bulito section, type early Refugian Stage. Ranges of diagnostic benthic foraminifers from Tipton (1980) are shown. Age interpretations based on planktic microfossils and paleomagnetism are from Warren and Newell (1980) and Prothero and Thompson (2001), respectively. Fm., Formation.

consistent diagnostic Bulitian benthic foraminiferal fauna observed in the various sections. Reexamination of the benthic foraminifers suggests that the strata assigned to the Bulitian in Arroyo el Bulito (type section; fig. 4.7) and Simi Valley (in part; fig. 4.13) sections should be assigned to the Ynezian Stage. These strata contain planktic microfossils diagnostic of zones P4 and CP5 through CP8. In the Simi Valley section, Paleocene species disappear and Eocene species appear between samples A7641 through SS586 (fig. 4.13). Planktic microfossils and paleomagnetism indicate this interval straddles the Paleocene/Eocene boundary. Assignment of this interval to the Bulitian Stage is tentative. No cosmopolitan benthic foraminifers diagnostic of the late Paleocene are recognized, but this may be due to taxonomic problems. In the Media Agua Creek (fig. 4.8) and Pacheco Syncline sections (fig. 4.14), strata interpreted as Bulitian should be assigned to the early Eocene, Penutian Stage. Planktic microfossils in these strata are assigned to zones P7 and CP10. Although Mallory (1959) indicated that Bulitian Stage occurred in the Devils Den and Lodo Gulch sections, the Bulitian Stage is not recognized in any recent studies (Berggren and Aubert, 1983; McDougall, 1989, 1993).

The Bulitian Stage is late Paleocene in age and probably coeval with planktic foraminiferal zones P5 through P6a and the coeval calcareous nannoplankton zone CP8 (fig. 4.2). The P5 to P6a interval is Paleocene, overlies the Ynezian Stage, underlies the Eocene, and occupies the position originally envisioned for the Bulitian Stage. This particular interval is missing from all the sections examined in this study and may be missing throughout the region. If present, the base of the Bulitian Stage could be identified by the first appearance *Aragonia aragonensis*. The upper boundary could be identified by the first appearance of numerous Eocene species and the last appearance of Paleocene cosmopolitan benthic foraminiferal species near the Bulitian/Penutian Stage boundary (figs. 4.3 and 4.4).

The Bulitian Stage is coeval with a series of rapid sea level fluctuations (Haq and others, 1987a,b, 1988; Johnson and others, 2005), major restructuring of the water masses and currents in the marine environment, and a change in deep water circulation (Thomas, 1990; Kennett and Stott, 1995). The Paleocene-Eocene Thermal Maximum (PETM), which occurs at the Paleocene/Eocene and Bulitian/Penutian Stage boundary, is marked by extinction of 30 to 50 percent of the benthic foraminiferal fauna (Thomas, 2006) (fig. 4.5).

## Penutian Stage

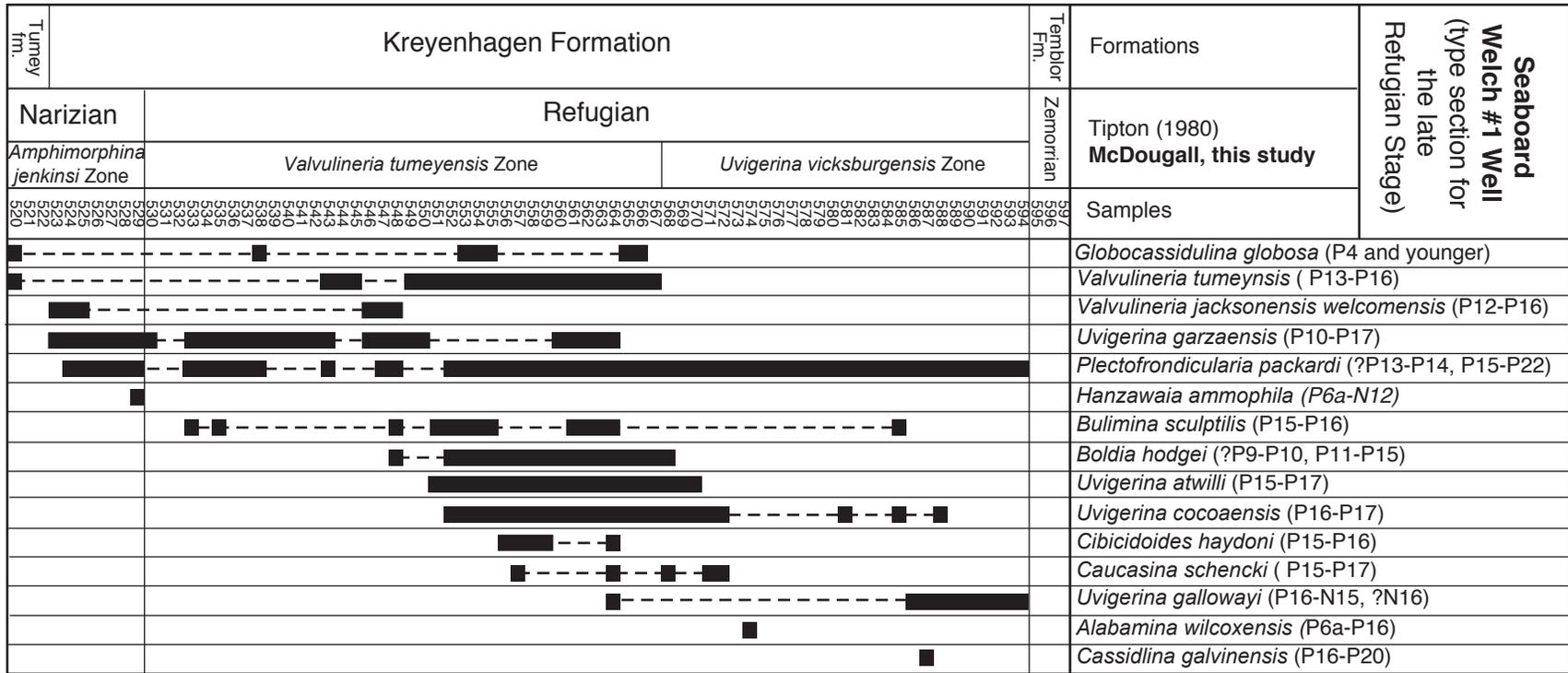
The type Penutian Stage and zones as described by Mallory (1959) in the Media Agua Creek section contains planktic microfossils assigned to zones P7 (part), as well as CP10 through CP11. Chron C22r occurs in the upper part of the type Penutian Stage. During the reexamination of the Media Agua Creek section the Paleocene/Eocene is

recognized between samples A7080 and A7079 (fig. 4.8). Sample A7079 contains a mixture of species that last appear in the Paleocene or first appear in the Eocene. Early Eocene benthic foraminiferal species are present in samples A7079 through A7037. This interval includes strata originally assigned to Mallory's Bulitian, Penutian, and Ulatisian Stages, and is coeval with planktic microfossil zones P6b through P9 and CP9 through CP12 (Poore, 1976; Almgren and others, 1988), and Chrons C22r through C22n (Prothero, 2001a) (fig. 4.8).

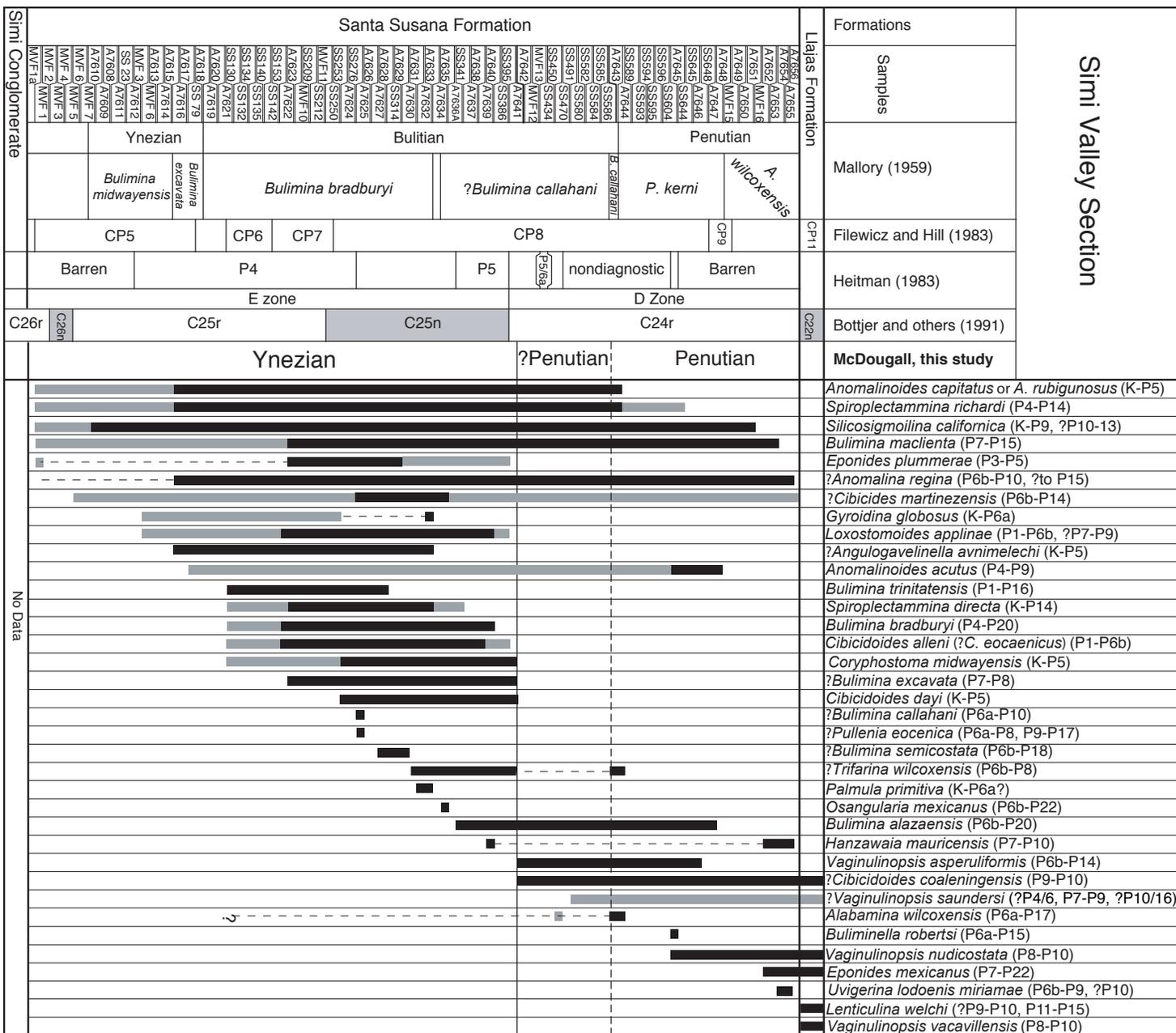
In the other sections examined, strata assigned to the Penutian Stage range from late Paleocene through middle Eocene—CP8, CP11, and P4 in Arroyo el Bulito, CP8 and CP9 in Simi Valley, and CP10 and CP12 in the Pacheco Syncline. Placement of the Paleocene/Eocene boundary in these sections occurs within strata defined as Ulatisian (Mallory, 1959; Mallory and others, 1998; between samples 30 and 29 in the Arroyo el Bulito section), within strata defined as Bulitian (Mallory, 1959; between samples A7641 and A7642 in the Simi Valley section), and at the base of the Bulitian Stage (Smith, 1957; Mallory, 1959; between samples Mf7966 and EB599 in the Pacheco Syncline) (figs. 4.7, 4.13, and 4.14). Revised age interpretations of these sections indicate that the base of the Penutian Stage coincides with the Paleocene/Eocene boundary and is coeval with planktic microfossil zones P6b and late CP8. Early Eocene faunas continue up section until they become non-diagnostic in the Arroyo el Bulito and Simi Valley sections or are overlain by middle Eocene microfossils (CP12) in the Pacheco Syncline section.

The Penutian Stage in California is recognized by the first and last appearances of numerous cosmopolitan benthic foraminifers (fig. 4.3). Species that last appear at or below the Paleocene/Eocene boundary or the base of the Penutian Stage include species used to identify the Paleocene Stages. First appearances at the base of the Penutian Stage include numerous *Bulimina* (*B. alazaensis*, *B. callahani*, *B. macilenta*, *B. semicostata*, and *B. tuxapamensis*), *Cibicides*, *Cibicides Anomalinoides*, and *Amphimorphina*, as well as the local species of *Uvigerina*, *Trifarina*, and *Vaginulinopsis*. The upper boundary of the Penutian Stage is recognized by the last appearance of *Loxostomoides applinae*, *Clavulina anglica*, and *Glomospira gordialis* and the first appearances of *Plectofrondicularia paucicostata*, *Uvigerina elongata*, *Vaginulinopsis nudicostata*, *V. vacavillensis*, and *Uvigerina churchi*.

The Penutian Stage, which follows the PETM, is characterized by a higher sea level, recolonization of the marine environments, and proliferation of buliminids. The faunal turnover at the Paleocene/Eocene boundary is global and followed by a recolonization (Berggren and Miller, 1989; Kennett and Stott, 1995). The global drop in sea level and Eocene canyon cutting event (ECCE, fig. 4.5), which occurs in zone P9, marks the end of the Penutian Stage (Haq and others, 1987a,b, 1988; Haq, 1991).

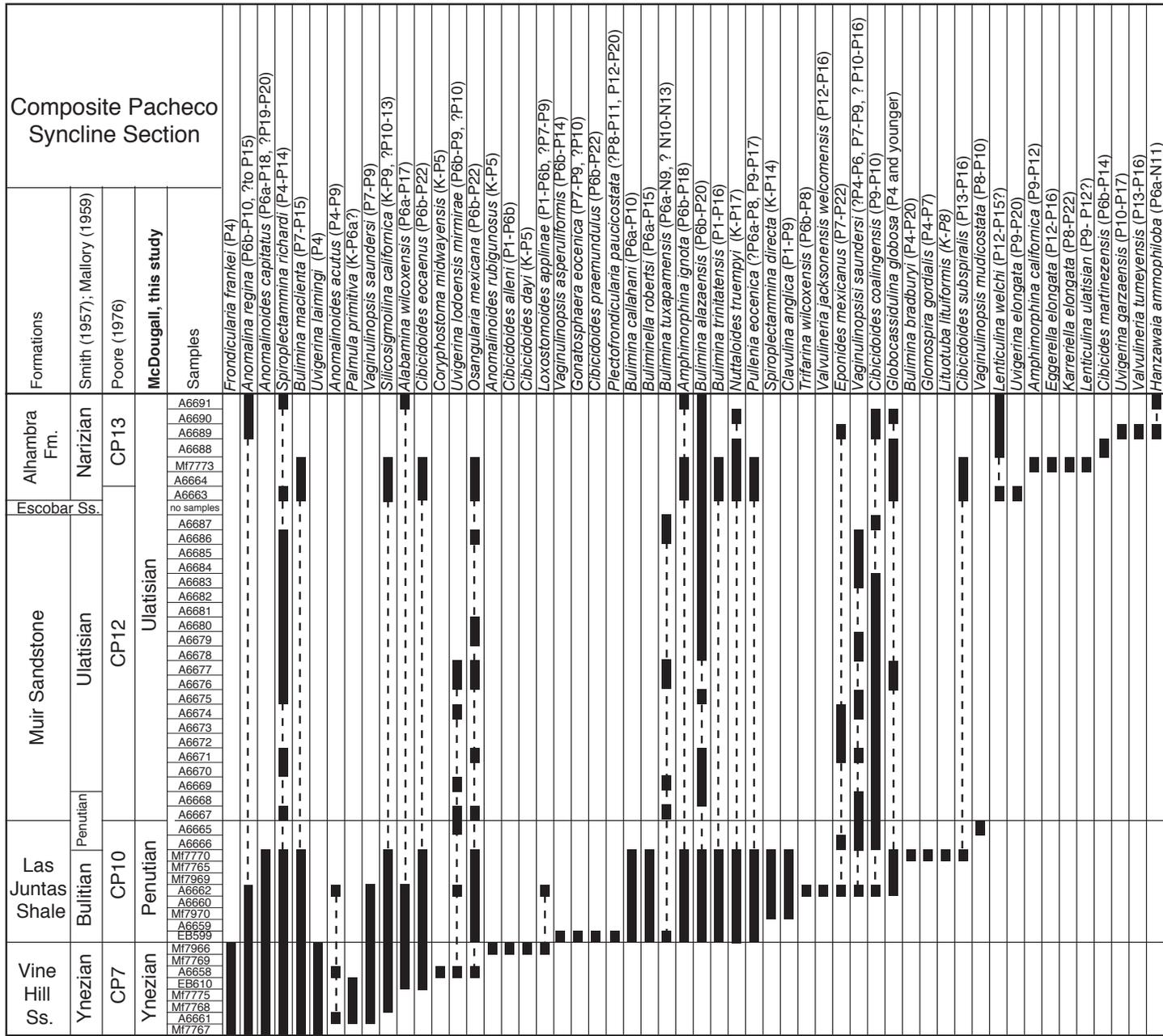


**Figure 4.12.** Biostratigraphy and ranges of diagnostic species in the Seaboard Welch Well #1, type section for the late Refugian Stage. Ranges of diagnostic benthic foraminiferal species from Tipton (1980) are shown. Informally named Tumey formation is Tumey formation of Atwill (1935). Fm., Formation.



**Figure 4.13.** Biostratigraphy and ranges of diagnostic species in the Simi Valley section. Black lines indicate benthic foraminiferal ranges based on the original work by Browning (1952), Grier (1953), and Browning and others (1998). Gray lines indicate the further extension of the species range based on the work of Heitman (1983). Planktic microfossil interpretations are from Filewicz and Hill (1983). Paleomagnetism are by Bottjer and others (1991).

SSXXX = Filewicz and Hill (1983) and Heitman (1983) numbers  
 MVFXX = Mallory (1959) numbers



**Figure 4.14.** Biostratigraphy and ranges of diagnostic species in the Pacheco Syncline based on studies by Smith (1957) and McDougall (unpublished paleontology reports). Planktic interpretations are based on work by Poore (1976). Fm., Formation; Ss., Sandstone.

### Ulatisian Stage

Mallory's type Ulatisian Stage in Vaca Valley occurs within planktic zones CP11 through CP12, and P9 (Vaughan, 1976; Poore and Bukry, 1983). In Media Agua Creek (type section for the zones), the Ulatisian Stage ranges in age from planktic foraminiferal zones P8 through P10, and CP12 through CP13 (Poore, 1976; Almgren and others, 1988). As suggested by Almgren and others (1988), the stage and zones are different ages. In the revised interpretation, the entire Vaca Valley section is Ulatisian in age and coeval with planktic foraminiferal zones P9 through P12, calcareous nanno-

plankton zones CP11 through CP13, and Chrons C22r through C20r (fig. 4.9). Because the adjacent stages are not exposed, the age of the upper and lower boundaries of the Ulatisian Stage is unknown. In the revised interpretation of the Media Agua Creek section, the Ulatisian Stage is recognized between samples A7038 and the top of the sampled section (sample A7007; fig. 4.8). The lower boundary of the Ulatisian Stage occurs within zone P9, although there may be a break in sedimentation that obscures the actual base of the stage (fig. 4.8). This interval is coeval with planktic zones P9 (late) and P10 and CP13. The upper part of this interval does not contain

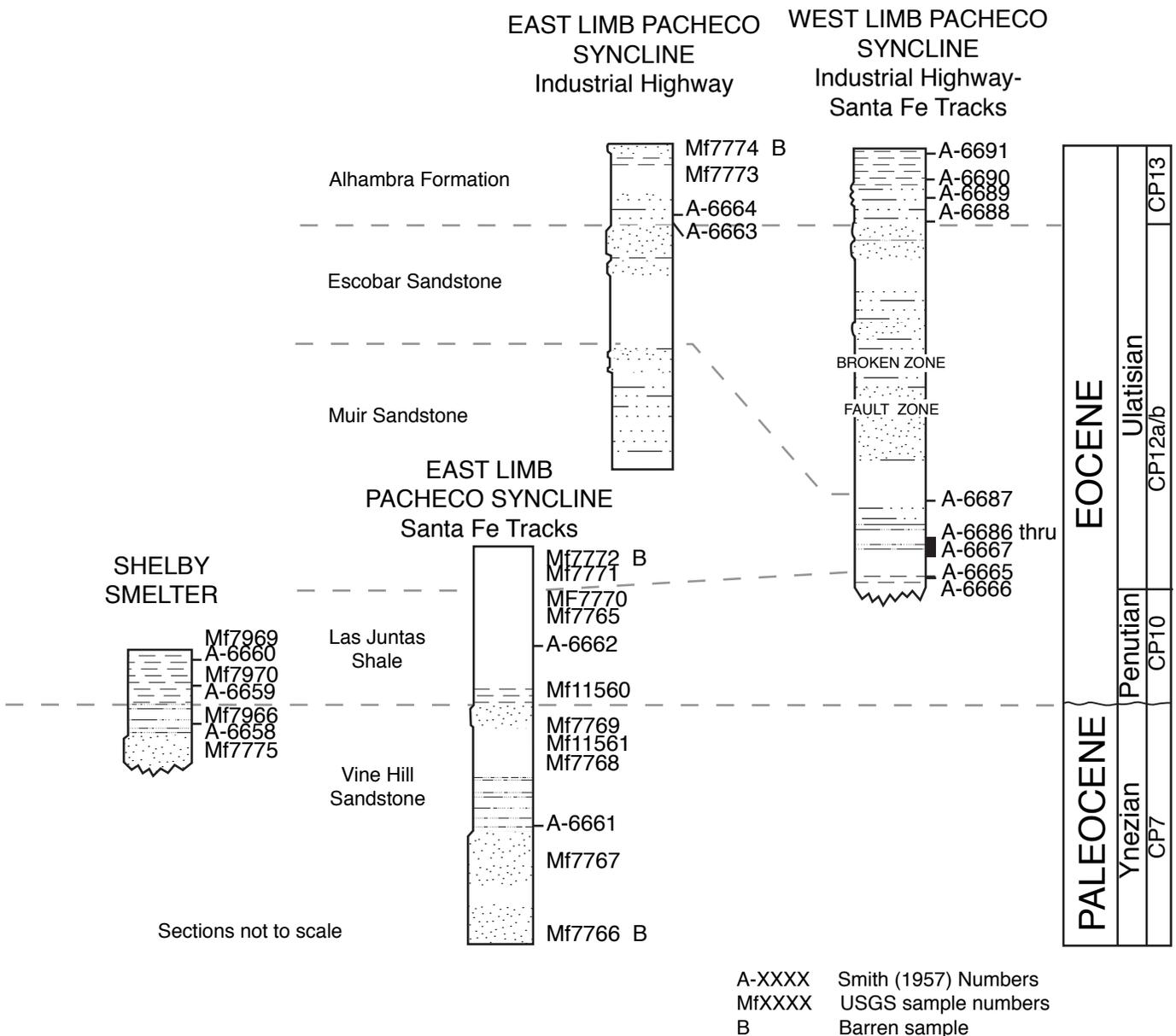


Figure 4.15. Correlation of the Pacheco Syncline sections.

planktic microfossils nor does it contain benthic foraminifers diagnostic of the Narizian Stage. Chron 20r is recognized at the top of the sampled section (Prothero and Brabb, 2001) (fig. 4.8).

The Ulatisian Stage was recognized by Mallory (1959; Mallory and others, 1998) in the Arroyo el Bulito, Devils Den, and Pacheco Syncline sections. In Arroyo el Bulito, Mallory's Ulatisian occurs with Paleocene microfossils and is reassigned to the Ynezian and Penutian Stages. The upper part of Mallory's Ulatisian does not contain diagnostic foraminiferal assemblages and is therefore considered Penutian or younger. In the Devils Den section, the Ulatisian was recognized at the base of the section (samples A7133-38 through C47D) and is still considered Ulatisian. In the Pacheco Syncline sections, both Mallory (1959) and Smith (1957) recognized a thick Ulatisian interval. In this reevaluation, the Ulatisian is recognized in samples A6667 through the top of the sampled section (fig. 4.14). This interval is coeval with planktic zones CP12 through CP13.

Although the upper and lower boundaries of the Ulatisian Stage are in question, the Ulatisian Stage is middle Eocene and appears to be coeval with zones late P9 through P12 or CP12 through CP13 (fig. 4.2). The lower boundary probably corresponds to a global drop in sea level and significant canyon cutting in zone P9 (fig. 4.5). The age discrepancy recognized by Almgren and others (1988) persists because the adjacent stages are not recognized in the type sections.

The lower boundary of the Ulatisian Stage can be recognized by the first appearances of *Karreriella elongata*, *Plectofrondicularia paucicostata*, *Lenticulina ulatisian*, *Uvigerina churchi*, *Uvigerina elongata*, and *U. garzaensis*; the last appearances of *Anomalinoides preacuta*, *Loxostomoides applinae*, *Lituotuba lituiformis*, and *Glomospira gordialis* near the base of the stage; and in most sections a significant change in water depth. The upper boundary of the Ulatisian Stage is marked by the last appearances of *Karreriella conversa*, *Bulimina callahani*, *Gonatosphaera eocenica*, *Bolivina explicata lodoensis*, *Hanzawaia mauriciensis*, *Vaginulinopsis vacavillensis*, and *V. nudicostata*, and the first appearances of *Cibicidoides subspiralis*, *Bulimina microcostata*, and *Valvulineria jacksonensis* (figs. 4.3 and 4.4). The Ulatisian/Narizian boundary is poorly defined because it does not occur in either of the Ulatisian type sections. Additional work is needed.

## Narizian Stage

Previous studies found that the Narizian Stage in California ranged in age from planktic zones P9 through P16 and CP12 through CP15; however, these interpretations were not based on the type section (Poore, 1976; Bukry and others, 1977; Poore, 1980; Warren, 1983; Almgren and others, 1988). Reevaluation of the type section of the Narizian Stage retains the boundaries as identified by Mallory (1959) and supports

the unconformity between the Kreyenhagen and Wagonwheel Formations noted by Almgren and others (1988). The age of the Narizian Stage cannot be determined in the type section because planktic microfossils were not examined in the type Narizian section and diagnostic cosmopolitan benthic foraminifers are not present. Chron C20n or C21n occurs within the Narizian interval and Chron C15r occurs in the lower Refugian strata. Therefore, the upper boundary of the Narizian Stage is older than Chron C15r. Because the upper boundary coincides with an unconformity, an unknown quantity of strata is missing.

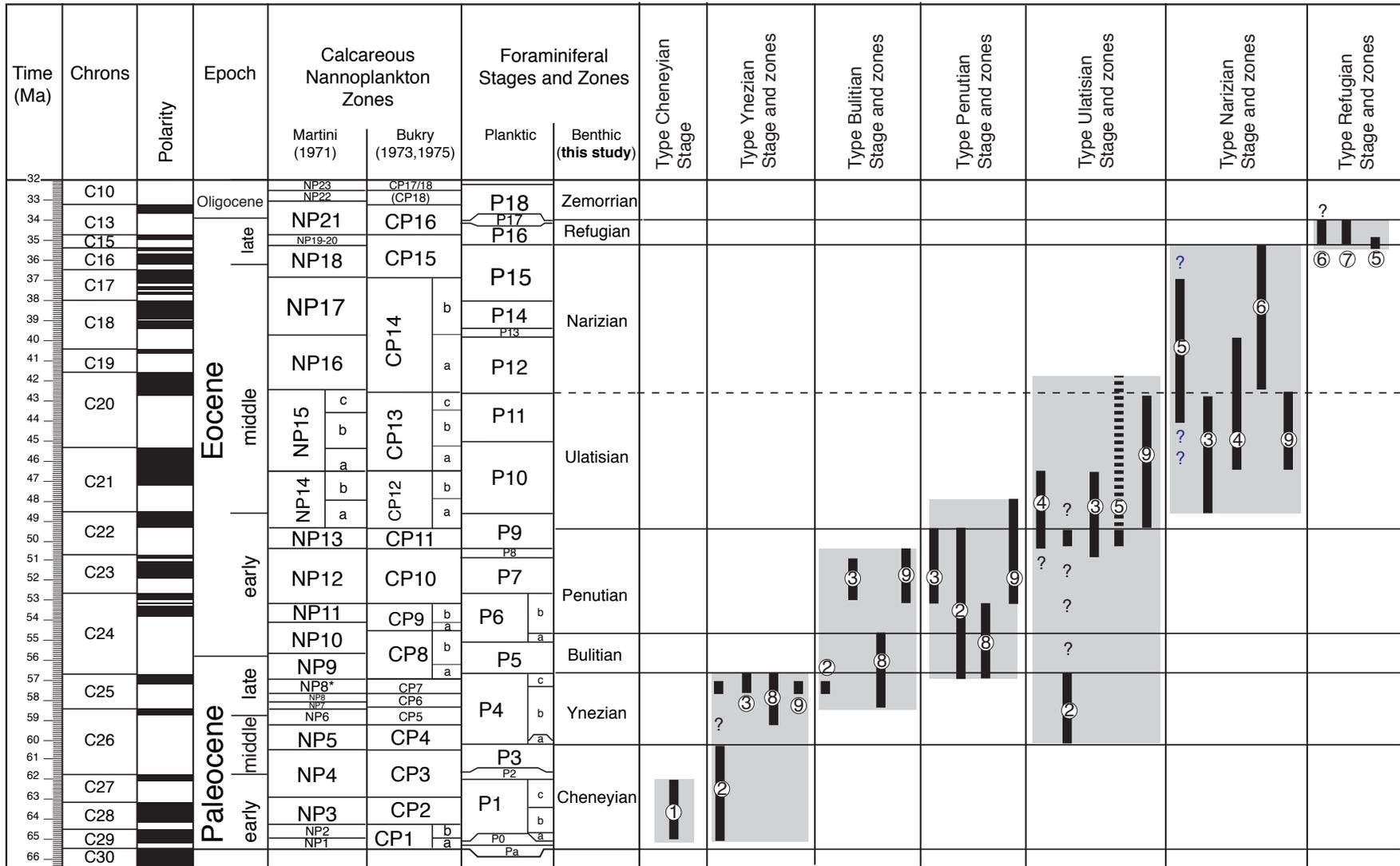
The Devils Den aqueduct section near the type Narizian section was examined by Berggren and Aubert (1983) and Warren (1983) and interpreted as containing Narizian benthic foraminifers, no planktic foraminifers, and calcareous nannoplankton assigned to zone CP13. Cosmopolitan benthic foraminifers in the interval assigned to the Narizian Stage indicate an age range coeval with zones P8 through P16. The benthic foraminiferal assemblages should be assigned to the Ulatisian, rather than to the Narizian Stage.

The Narizian Stage was recognized by Mallory (1959) in the Media Agua Creek, Vaca Valley, upper Arroyo el Bulito, and Pacheco Syncline sections. In this study, foraminifers in the Media Agua Creek, Pacheco Syncline, and Vaca Valley sections were previously shown to be no younger than Ulatisian. Narizian benthic foraminifers occur in the upper Arroyo el Bulito section underlying the type Refugian Stage. These assemblages are Narizian and coeval with calcareous nannoplankton zones NP16 through NP18 and Chrons C16n and C15r.

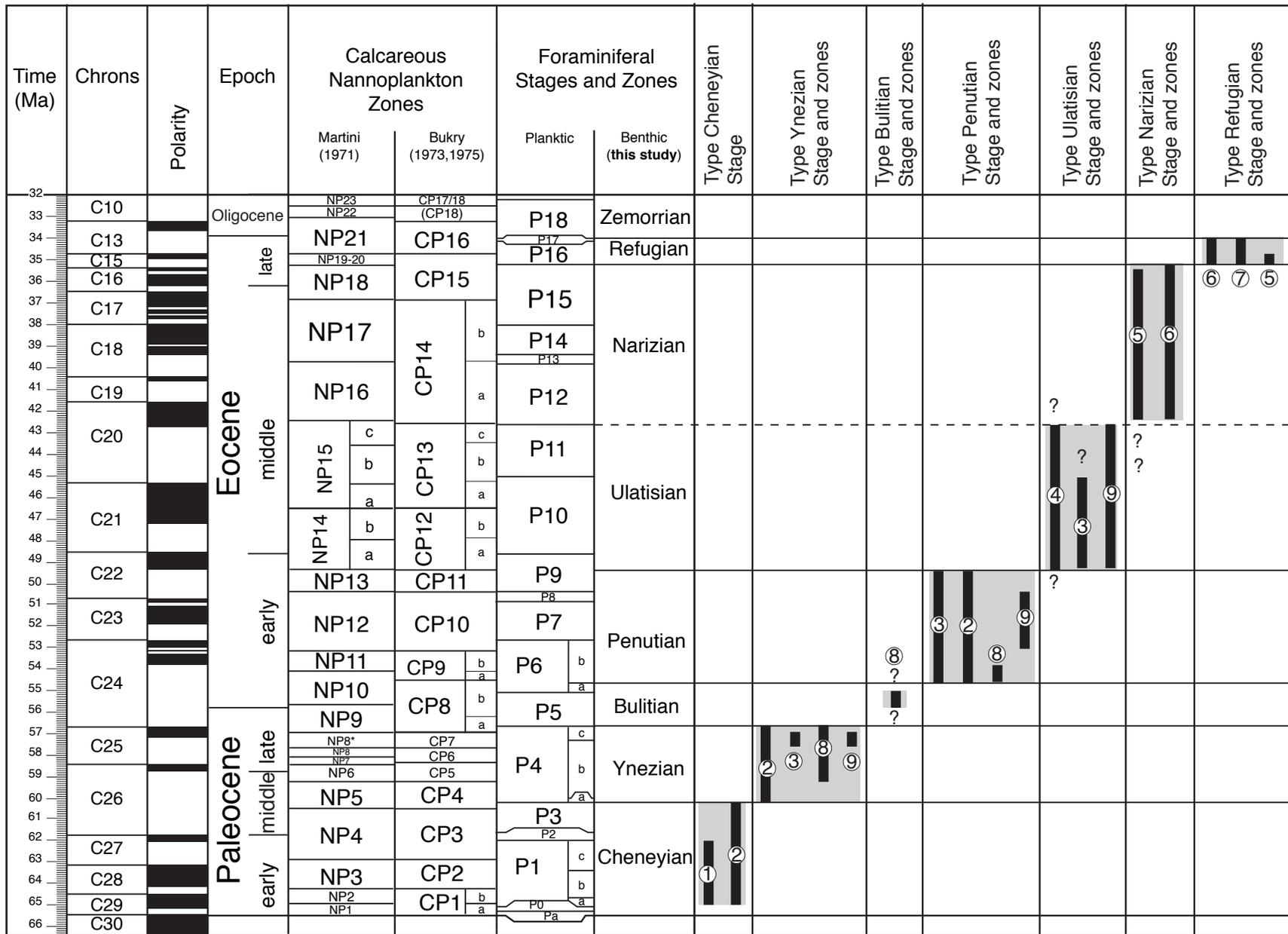
The Narizian Stage appears to be middle to late Eocene in age and coeval with planktic foraminiferal zones P12 through P15, calcareous nannoplankton zones CP14 through CP15a (NP16 through NP18), and older than Chron C15r. Considerable work needs to be done on this stage to determine the age and find a type section or boundary stratotypes for the stage. The transition from Ulatisian Stage to the Narizian Stage needs additional study as this boundary appears to coincide with a change in sea level near the base of zone P12 (fig. 4.5), but the rapidly changing sea level and associated erosion may obscure the early part of this stage. Age diagnostic cosmopolitan species are not helpful in clarifying the boundary as few first or last appearance datums occur between zones P12 and P15. Local species may be more useful but are generally less accurately dated so their age ranges are still in question. The transition from the Narizian Stage to the Refugian Stage is marked by numerous first and last appearance datums due to a global deep-sea hiatus and reorganization of abyssal and bathyal water masses (Keller and others, 1987; Berggren and Miller, 1989).

## Refugian Stage

The type Refugian Stage ranges in age from planktic zones P16 through P17 and NP19 through NP21. Chrons C15r



**Figure 4.16.** Age of the type stages and zones based on planktic microfossils and paleomagnetic interpretations. Time scale is the same as in figure 4.2. The duration of each of the type stages is plotted against the time scale to show the extent of each stage. The sections are labeled as follows: 1=Jergins Cheney Ranch Well No. 1; 2=lower Arroyo el Bulito; 3=Media Agua Creek; 4=Vaca Valley; 5=Devils Den; 6=upper Arroyo el Bulito; 7=Seaboard Welch Well # 1; 8=Simi Valley; and 9=Pacheco Syncline.



**Figure 4.17.** Revised ages of the type stages and zones based on reevaluation of the benthic foraminiferal assemblages. The duration of each of the type stages is plotted against the time scale to show the extent of each stage. The sections are labeled as follows: 1=Jergins Cheney Ranch Well No. 1; 2=lower Arroyo el Bulito; 3=Media Agua Creek; 4=Vaca Valley; 5=Devils Den; 6=upper Arroyo el Bulito; 7=Seaboard Welch Well # 1; 8=Simi Valley; and 9=Pacheco Syncline.

through C13r are recognized in Refugian strata (fig. 4.11). No chronostratigraphic data are available for the Seaboard Welch Well #1. Cosmopolitan benthic foraminifers indicate that the Refugian interval in the Seaboard Welch Well #1 is possibly as old as P15 and as young as P17. Additional Refugian sections in the Santa Cruz Mountains (Sullivan, 1964; Fairchild and others, 1969; Smith, 1971; Poore and Brabb, 1977; McDougall, 1983; Poore and Bukry, 1983; Warren, 1983; Prothero and others, 2001) also contain microfossils indicative of planktic foraminiferal zones P16 and P17 and calcareous nannoplankton zones CP15 and CP16a. Paleomagnetic analysis of the sections indicates the presence of Chrons C16n(?) through C13r (Prothero and others, 2001).

The age of the Refugian Stage is interpreted as late Eocene and coeval with planktic zones P16 and P17, CN15 and CP16a, and Chrons C16n(?) through C13r. This interval is bracketed by a deep-sea hiatus (PH, fig. 4.5) that coincides with the onset of circum-Antarctic circulation and global changes in circulation patterns, and a deep-sea hiatus (PH, fig. 4.5) that coincides with a short-term climatic change recognized in the Pacific Ocean (Keller and others, 1987; Berggren and Miller, 1989).

Only a few cosmopolitan species can be used to recognize the Refugian Stage. Most species have long ranges that begin in the early to middle Eocene and extend into the Oligocene (figs. 4.11 and 4.12). *Buliminella robertsi* and *Bulimina macilenta* last appear at the Narizian/Refugian boundary, and *Alabamina wilcoxensis*, *Bulimina trinitaentensis*, *Cibicides subspiralis*, *Pullenia eocenica*, and *Nuttaloides truempyi* last appear at or near the Refugian/Zemorrian boundary. These species are not common in the California Refugian sections due to the paleoenvironment. Diagnostic local species found in the assemblages include the last appearances of *Anomalina regina*, *Bulimina microcostata*, *Lenticulina welchi*, *Spiroplectammina richardi*, and *Uvigerina churchi* and the first appearances of *Anomalina californiensis*, *Cassidulina galvinensis*, *Uvigerina cocoaensis*, and *U. gallowayi* at the Narizian/Refugian boundary. A faunal turnover in planktic foraminiferal zone P15 appears to have resulted in a proliferation of local species (Berggren and Miller, 1989). The Refugian/Zemorrian boundary is marked by the last appearances of *Boldia hodgesi*, *Bulimina sculptilis*, *Caucasina schencki*, *Cibicides haydoni*, *Cibicidoides coalingensis*, *Eggerella elongata*, *Uvigerina atwilli*, *Uvigerina cocoaensis*, *Valvulineria jacksonensis*, and *Valvulineria tumeyensis*, at or near the boundary. These ranges are not as well documented as the cosmopolitan species and therefore may be subject to change as more data becomes available.

## Conclusions

Reexamination of the Paleogene Stages and their type sections in light of new studies, more rigorous taxonomy, and global rather than local species ranges resolves most of the time transgressive problems associated with the California

benthic foraminiferal stages. Recognizing breaks or unconformities in the type sections also aids in eliminating much of the time transgressiveness in the stage boundaries. Clarification of the stage and zonal criteria of the Paleogene Stages suggests that the Paleocene is composed of the Cheneyian, Ynezian, and Bulitian Stages and the Eocene is composed of the Penutian, Ulatisian, Narizian, and Refugian Stages. Each of the stages, however, needs some additional work to establish adequate type sections or boundary stratotypes that document the boundaries of this stage.

The Paleocene Stages include the Cheneyian, Ynezian, and Bulitian. The Cheneyian Stage is coeval with planktic zone P1 through P3. Faunal lists were never published for this stage nor was a type section officially designated. Further, the Cheneyian/Ynezian Stage boundary is not represented in any section examined for this study and may be obscured in California strata due to erosional events. The Ynezian Stage is coeval with planktic zone P4 and the Bulitian Stage is thought to be coeval with zones P5 and P6a. The boundaries of the Ynezian Stage are obscured by unconformities and strata that should be assigned to the Bulitian Stage are largely missing from the California sections. Foraminiferal species diagnostic of the Ynezian Stage are widespread, whereas foraminiferal species diagnostic of the Bulitian Stage are often found reworked into the early Eocene assemblages. New type sections or boundary stratotypes for these stages need to be designated.

In the Eocene, the Penutian Stage is coeval with planktic zones P6b through early P9 (no younger than the overlap between P9 and CP11), the Ulatisian Stage is coeval with P9 (younger than CP11) through P11, the Narizian Stage is coeval with zones P12 through P15, and the Refugian Stage is coeval with zones P16 and P17 (fig. 4.17). The lower boundary of the Penutian Stage in the type section and other sections examined is either an unconformity or a barren or sparsely fossiliferous interval with no diagnostic species. The upper boundary in the type section is conformable with the overlying Ulatisian Stage. The upper and lower limits of the Ulatisian Stage are not observed in the sections examined for this study except for the lower Ulatisian boundary in the Media Agua Creek Section where the Ulatisian conformably overlies the Penutian Stage. The limits of the Narizian Stage are either not observed in most other sections or where observed, there are no other chronostratigraphic data to indicate the age of the boundary. Similar problems exist with the Refugian Stage and more chronostratigraphic data are needed to establish the age of the boundaries.

Cosmopolitan and local benthic foraminiferal species are present in the California sections. The most useful of these species and their ranges are given in figures 4.3 and 4.4. Few species are identified for the Cheneyian and Bulitian Stages. Considerable work needs to be done on the Cheneyian Stage to separate it from the underlying Cretaceous strata. The Bulitian Stage is poorly represented in California since it coincides with the Paleocene/Eocene Thermal Maximum and several sea level changes. Numerous first and last appearance datums of benthic foraminiferal species identify the other stage boundaries.

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**Appendix**

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## Appendix 4.1 - Taxonomic Notes

*Alabamina wilcoxensis* Toulmin - - Smith (1957), p. 187, pl. 28, fig. 8. - - Mallory (1959), p. 227, pl. 19, fig. 10. - - Mallory (1970), p. 138. - - Tipton (1980), p. 271. - - Heitman (1983), fig. 4 (list). = *Alabamina scitula* Bandy - - Vaughan (1976), p. 67. = *Eponides beisseli* (White) - - Smith (1957), p. 182, pl. 27, fig. 7. - - Mallory (1959), p. 237. - - Browning and others (1998), p. 149 (list). - - Mallory and others (1998), p. 256 (list). = *Alabamina wilcoxensis californica* Mallory - - Kleinpell and Mallory (1998), p. 234, 237 (list). = *Alabamina kernensis* Smith (1956), p. 99, pl. 15, figs. 3, 4. - - Tipton (1980), p. 265 (list), 274.

**Range:** Mallory (1959) gave the range of *A. wilcoxensis* as early Bulitian to late Penutian and cites its presence in the Media Agua Creek and Devils Den sections. Except for a questionable occurrence in the strata assigned to zone P4 in the Media Agua Creek section, *A. wilcoxensis* ranges from sample A7075 to A7088 (Bulitian to Penutian, Mallory, 1970). This interval has, however, been assigned to the early Eocene Penutian Stage (fig. 4.8) and planktic zones P7 and CP10 (Poore, 1976; Almgren and others, 1988). *Alabamina wilcoxensis* is listed in the Devils Den section (Kleinpell and Mallory, 1998) in the Narizian interval coeval with Chrons C21n or C20n through C15n (Prothero, 2001a). Other questionable Paleocene occurrences of *A. wilcoxensis* are noted in the Arroyo el Bulito, Simi Valley, and Pacheco Syncline sections (Smith, 1957; Heitman, 1983; Mallory and others, 1998; McDougall, unpublished paleontology reports). In other sections examined for this study, *A. wilcoxensis* is found in Penutian through Refugian strata coeval with zones P7 through P16. *Alabamina wilcoxensis* resembles and may be a junior synonym of the cosmopolitan species *A. dissonata*, which ranges from zones P6a through P17 (latest Paleocene through late Eocene; Tjalsma and Lohmann, 1983). The range of *A. wilcoxensis* is P6 through P16 with rare questionable occurrences in the Paleocene P4 zone.

**Ecology:** *Alabamina dissonata* has a wide bathymetric distribution in the early Eocene but in the middle and late Eocene it is restricted to deeper sites (>2,000 m) (Tjalsma and Lohmann, 1983). *A. wilcoxensis* has a similar range.

*Amphimorphina californica* Cushman and McMasters - - Laiming (1940), p. 547 (list) - - Mallory (1959), p. 215, pl. 18, fig. 6.

**Range:** Mallory (1959) restricts *A. californica* to the late Ulatisian, *A. californica* zone; occurrences listed are in sections not examined in this study. *A. californica* occurs only in the Ulatisian of the Pacheco Syncline section (fig. 4.14) examined for this paper and a tentative range of P9 through P12 is assigned to this species.

*Amphimorphina ignota* Cushman and Siegfus - - Martin (1943), p. 9 (list). - - Mallory (1959), p. 215-216, pl. 18, fig. 7; pl. 33, fig. 9. - - Mallory (1970), p. 100. - - Gibson (1976), Table 2 (list). - - Tjalsma and Lohmann (1983), p. 22, pl. 14, fig. 18. - - Berggren and Aubert (1983), pl. 2, fig. 7. - - Kleinpell and Mallory (1998), p. 234 (list). - - Mallory and others (1998), p. 255, 258 (list). = *Amphimorphina* (?) sp. - - Smith (1957), p. 172, pl. 24, fig. 1.

**Range:** Although Mallory (1959) gives range as late Ynezian to early Narizian (Paleocene through Eocene), the late Ynezian occurrences in the Media Agua Creek section (sample A7078 to A7017 and questionably as high as A7007), are assigned to planktic foraminiferal zone P6b through P10 (Poore, 1976) and thus are Eocene in age. *Amphimorphina ignota* is also reported from the Arroyo el Bulito section by Gibson (1976), in the Ynezian and Bulitian (P4 and P5) but taxonomic problems in this section do not necessarily support this Paleocene occurrence. Tjalsma and Lohmann (1983) give a range of Eocene and find this species occurring sporadically throughout the Eocene (zones P6b through P18).

*Angulogalvelinella avnimelechi* (Reiss) - - van Morkhoven and others (1986), p. 344-346, pl. 112. - - *Gyroidina browni* Grier (1953), p. 92, pl. 1, fig. 8. - - Browning and others (1998), p. 141, 145 (list).

**Range:** *Angulogalvelinella avnimelechi* ranges from the Cretaceous through late Paleocene (P5) (van Morkhoven and others, 1986). This species, previously recognized in the Simi Valley section as *Gyroidina browni*, is present in the Ynezian portion of the section, coeval with P4 and CP5 through CP8 (fig. 4.13) and the Cheneyian Stage (Goudkoff, 1945). It may also be lumped with various *Gyroidina* species in other studies.

*Anomalina californiensis* Cushman and Hobson - - Smith (1956), p. 100, pl. 16, fig. 3. - - Tipton (1980), p. 274.

**Range:** *Anomalina californiensis* occurs in Refugian through early Saucesian strata in California (Kleinpell, 1938; Smith, 1956; Tipton, 1980). The range of this species is tentatively given as P16 through N5.

*Anomalina regina* Martin - - Smith (1957), p. 191, pl. 29, fig. 8. - - Mallory (1959), p. 261, pl. 38, fig. 6a, b, c. - - Mallory (1970), p. 154, pl. 14, fig. 3a-c. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 140, 143 (list). = *Anomalina* cf. *A. regina* Martin - - Mallory (1970), p. 154, pl. 14, fig. 5. - - Browning and others (1998), p. 149 (list). =

*Anomalina regina minor* Smith (1957), p. 192, pl. 29, figs. 2 and 4. - - Mallory (1959), p. 261, pl. 23, fig. 6a, b, c. - - Browning and others (1998), p. 149 (list). - - Kleinpell and Mallory (1998), p. 237 (list). = *Anomalinoides welleri* (Plummer) - - Berggren and Aubert (1983), p. 16.

**Range:** Although Mallory (1959) gives the range of *A. regina* as early Bulitian (late Paleocene) to late Penutian (early Eocene), this species ranges from planktic zone P6b through P10, and questionably up to P15 (McDougall, 1988). Bulitian localities listed by Mallory (1959) are from the Lodo Gulch section (Martin, 1943), Simi Valley (Browning, 1952; Grier, 1953), Pacheco Syncline (Smith, 1957), and Media Agua Creek (Mallory, 1959, 1970). The oldest occurrence cited by Martin (1943; sample I-X7) is in strata assigned to planktic foraminiferal zones P5 (Poore, 1976; Berggren and Aubert, 1983), however, Berggren and Aubert (1983) have not found *A. regina* in strata older than P8 in the Lodo Gulch section. *Anomalina regina* in the Simi Valley section occurs in the Paleocene but taxonomic problems in this section make these specimens suspect. The other Bulitian localities listed by Mallory (1959) are in strata assigned to P6b or younger zones. The variety *A. regina minor* occurs in strata as young as late Narizian (late Eocene) (Mallory, 1959). The range of *A. regina* is therefore P6b through P10 and questionably to P15.

**Ecology:** Along the East Pacific margin, *A. regina* has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (*Melonis regina*, Ingle, 1980).

*Anomalinoides acutus* Plummer = *Anomalina acuta* Plummer - - Mallory (1959), p. 258. = *Anomalinoides acuta* (Plummer) - - Berggren and Aubert (1983), p. 11, pl. 5, figs. 1-3. = *Cibicides alazaensis* (Nuttall) - - Smith (1957), p. 195, pl. 29, fig. 10. = *Cibicidoides midwayensis* (Plummer) - - Smith (1957), p. 96, pl. 30, fig. 4. = *Cibicides susanaensis* Browning in Mallory (1959) - - Mallory (1959), p. 271, pl. 32, fig. 11, 12. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 150 (list). - - Mallory and others (1998), p. 255 (list). = *Cibicidoides durhami* Smith (1957), p. 196, pl. 32, figs. 3, 4.

**Range:** Mallory (1959) gives the range of *A. acutus* as restricted to the Ulatisian Stage and of *C. susanaensis* as lower Ynezian to lower Bulitian in the Santa Barbara area. The Arroyo el Bulito and Simi Valley sections reexamined in this paper contain *A. acutus* in the Ynezian and Bulitian intervals coeval with zones P4 through P6a and CP5 through CP9 (Poore, 1976; Filewicz and Hill, 1983; Heitman, 1983). Berggren and Aubert (1983) also report this species

from the Lodo Formation where it ranges from P5 through P9. The range of *A. acutus* is tentatively given as P4 through early P9, although it may be extended in the future.

**Ecology:** *Anomalinoides acutus* has an upper depth limit in the outer shelf biofacies (50 to 150 m) (Ingle, 1980).

*Anomalinoides capitatus* (Gumbel) - - van Morkhoven and others (1986), p. 276-278, pl. 92, figs. 1-2. = *Gavelinella capitata* (Gumbel) - - Tjalsma and Lohmann (1983), p. 31, pl. 16, figs. 4-5. = *Anomalina dorri* Cole - - Martin (1943), p. 9 (list). - - Heitman (1983), fig. 4 (list). = *Anomalina dorri aragonensis* Nuttall - - Smith (1957), p. 191, pl. 31, figs. 1-2. - - Mallory (1959), p. 259, pl. 35, fig. 5. - - Almgren and others (1988), fig. 5 (list). = *Anomalina aragonensis* Nuttall - - Martin (1943), p. 9 (list). - - Berggren and Aubert (1983), p. 10 (list), pl. 5, figs. 7, 8, 9. = *Gavelinella dorri* var. *aragonensis* (Nuttall). - - Browning and others (1998), p. 141, 145 (list). - - Kleinpell and Mallory (1998), p. 235 (list). - - Mallory and others (1998), p. 256, 258 (list). = *Anomalina* (?) sp. - - Smith (1957), p. 192, pl. 29, fig. 7. = *Gavelinella rubiginosus* - - Mallory (1970), p. 155-156. *Gavelinella* cf. *G. rubiginosus* - - Mallory (1970), p. 156, pl. 14, fig. 2.

**Range:** A late Paleocene (P6a) through early Oligocene (P18) range with questionable occurrences in early Oligocene zones P19 and P20 is given by van Morkhoven and others (1986). Forms transitional between *A. rubiginosus* and *A. capitatus* have been observed in the middle Paleocene (P4) and early Eocene (P6b to P11) (van Morkhoven and others, 1986). In California, Berggren and Aubert (1983) found *A. capitatus* (*A. aragonensis*) in the early Eocene Lodo (P6 to P9) and Kreyenhagen (P8 to P9) Formations. Almgren and others (1988) give the range of *A. dorri aragonensis* as zones E and pseudo-C corresponding to nannofossil zones CP5 through CP11 (planktic foraminiferal zones P4 through P9). The older occurrences noted by Almgren and others (1988) have not been examined and may be the transitional forms noted by van Morkhoven and others (1986). Mallory (1959) found this species to be widespread throughout California, ranging from Ynezian through Ulatisian. In sections examined for this study, *A. capitatus* was found in the Paleocene, Ynezian and Bulitian Stages of the Arroyo el Bulito (fig. 4.7), Simi Valley (fig. 4.13) and Pacheco Syncline (fig. 4.14) sections and in the Eocene of most other sections (fig. 4.8). Paleocene specimens in the Arroyo el Bulito, Simi Valley, and Pacheco Syncline sections may be the transitional forms or may be *A. rubiginosus*; more

recent work in California has failed to recognize *A. capitatus* in the Paleocene portion of these sections. The Paleocene occurrences of this species are therefore assumed to be misidentified and are probably *A. rubiginosus* since this species was rarely reported from California strata in these older works. The upper limit of this species range appears to be in the Oligocene as it is present throughout the Eocene sections.

**Ecology:** *Anomalinoides capitatus* was primarily a bathyal species but ranged to abyssal depths (van Morkhoven and others, 1986). Ingle (1980) considers this species to have an upper depth limit in the lower bathyal biofacies ( $\geq 2,000$  m).

*Anomalinoides rubiginosus* Cushman - - van Morkhoven and others (1986), p. 366-368, pl. 119.

**Comments:** *Valvulineria lillisi* of Mallory (1959, p. 231, pl. 20, fig. 7) and Goukoff (1945, Table II) is probably a synonym of *Anomalinoides rubiginosus* based on the coarse pores and umbo regions that more closely resemble *A. rubiginosus*.

**Range:** *Anomalinoides rubiginosus* ranges from late Cretaceous (Campanian) through Paleocene (P5) (van Morkhoven and others, 1986). This species was not recognized by Mallory (1959) or other earlier workers, but is recognized in recent work in the Paleocene Vine Hill Sandstone (fig. 4.14).

**Ecology:** *Anomalina rubiginosus* is a middle neritic to abyssal species (50 m to  $>2,000$  m) (van Morkhoven and others, 1986).

*Anomalinoides praeacuta* Vasilenko - - Tjalsma and Lohmann (1983), p. 4, pl. 4, fig. 10, pl. 10, figs. 8a-b.

**Range:** *Anomalinoides praeacuta* ranges from Paleocene zone P1 to early Eocene zone P6b (Tjalsma and Lohmann, 1983). This species was not recognized in California strata by earlier workers. It is present in the Paleocene of the Lodo Gulch section (Berggren and Aubert, 1983; Israelsky, unpublished data).

*Aragonia aragonensis* (Nuttall) = *Bolivina aragonensis* (Nuttall) - - Mallory (1959), p. 199-200, pl. 28, fig. 19a-b. - - Mallory (1970), p. 112. - - Kleinpell and Mallory (1998), p. 234 (list). = *Aragonia aragonensis* (Nuttall)- - Berggren and Aubert (1983), pl. 2, figs. 15-17. - - Tjalsma and Lohmann (1983), p. 23, pl. 11, figs. 2a-b. - - van Morkhoven and others (1986), p. 308-314, pl. 101a, figs. 1-3; pl. 101B, figs. 1-4; pl. 101C, figs. 1-3.

**Range:** The range of *A. aragonensis* is late Paleocene (P5) through latest middle Eocene (P14) (Tjalsma and Lohmann, 1983; van Morkhoven and others,

1986). Mallory (1959) gives the range as upper Ynezian to lower Narizian. The Ynezian occurrences are from Media Agua Creek but revision of the age of this section indicates that this species first appears in the mixed interval between the Ynezian and the Penutian and continues to the top of the Penutian Stage (fig. 4.8). Although Ynezian occurrences were noted in the Arroyo el Bulito section by Gibson (1976), conformity of the taxonomic designations with the present study has not been established so specimens designated *A. aragonensis* by Gibson may not be consistent with this study. Other occurrences in the section reexamined for this paper included an early Narizian occurrence in the Devils Den section.

**Ecology:** Along the East Pacific margin, *A. aragonensis* has an upper depth limit in the upper bathyal biofacies (150 to 500 m) (Ingle, 1980) but is considered primarily a lower bathyal and abyssal form (van Morkhoven and others, 1986).

*Boldia hodgei* (Cushman and Schenck) - - McDougall (1980), p. 33, pl. 29, fig. 4-6. - - Tipton (1980), p. 272. = *Cibicides hodgei* Cushman and Schenck - - Smith (1956), p. 101, pl. 16, fig. 1. - - Mallory (1959), p. 265, pl. 24, fig. 6. - - Tipton (1980), p. 265 (list), 274. = *Cibicidina hodgei*? (Cushman and Schenck) - - Kleinpell and Mallory (1998), p. 238 (list). = *Cibicides* cf. *C. hodgei* Cushman and Schenck - - Boyd (1998), p. 125 (list). = *Cibicidina* cf. *C. hodgei* (Cushman and Schenck) - - Kleinpell and Mallory (1998), p. 238 (list).

**Range:** Mallory (1959) and Tipton (1980) report this species ranging from the late Narizian through Refugian and note that there are some reports of this species occurring in older deposits but these are thought to be the result of misidentification. The range of *B. hodgei* is tentatively given as P15 through P17.

*Bolivina explicata lodoensis* Mallory (1959), p. 200, pl. 16, fig. 19a, b. - - Mallory (1970), p. 112-113, pl. 7, fig. 6. - - Vaughan (1976), p. 67. - - Berggren and Aubert (1983), p. 11 (list).

**Range:** *Bolivina explicata lodoensis* ranges from early Bulitian through late Ulatisian (Mallory, 1959). The early Bulitian and Penutian occurrences in the Media Agua Creek section (samples A7075 through A7088) are in assemblages assigned to planktic zone P7 (fig. 4.8). Ulatisian occurrences are in the Oil City section in strata assigned to planktic foraminiferal zones P10 (Mallory, 1959; Poore, 1976) and in the Lodo Gulch section (Berggren and Aubert, 1983; Israelsky, unpublished data; species not listed by Mallory, 1959 or Martin, 1943). *Boliv-*

*ina explicata lodoensis* was recognized by Berggren and Aubert (1983) in Lodo Gulch in strata assigned to early Eocene zones P8 and P9. The range of *B. explicata lodoensis* is from early to middle Eocene zones P7 to P10.

*Bolivinooides delicatulus* (Cushman) - - Mallory and others (1998), p. 254, 255 (list). - - van Morkhoven and others (1986), p. 337-339, pl. 110. = ? *Bolivinooides stewarti* Mallory (1959), p. 203, pl. 16, fig. 27 - - Mallory (1970), p. 99, pl. 7, fig. 9. - - Gibson (1976), Table 2 (list). - - Mallory and others (1998), p. 254, 255 (list).

**Range:** *Bolivinooides delicatulus* ranges from the Cretaceous through late Paleocene (P6a) (van Morkhoven and others, 1986). Mallory (1959) and Mallory and others (1998) restricted this species to the late Ynezian, citing its presence in the Media Agua Creek and Arroyo el Bulito sections; however Mallory and others (1998) also indicate that this species last appears in the Bulitian Stage. Both occurrences fall within the range given by van Morkhoven and others (1986).

*Bulimina alazaensis* Cushman - - Smith (1957), p. 173, pl. 24, fig. 12. - - Mallory (1959), p. 187, pl. 36, fig. 15a, b, c. - - Tjalsma and Lohmann (1983), p. 24, pl. 14, fig. 4. = *Bulimina adamsi* Cushman and Parker - - Mallory (1959), p. 187, pl. 41, fig. 12. - - Mallory (1970), p. 103, pl. 6, fig. 3. - - Boyd (1998), p. 122, 123 (list). - - Mallory and others (1998), p. 258 (list). = *Bulimina corrugata* Cushman and Siegfus - - Smith (1956), p. 95, pl. 13, fig. 7. - - Smith (1957), p. 174, pl. 24, fig. 8. - - Mallory (1959), p. 189, pl. 28, fig. 13a, b. - - Mallory (1970), p. 105. - - Vaughan (1976), p. 68. - - Tipton (1980), p. 265 (list), 274. - - Almgren and others (1988), fig. 5 (list). - - Boyd (1998), p. 125. - - Kleinpell and Mallory (1998), p. 234, 237 (list). - - Mallory and others (1998), p. 258 (list). = *Bulimina truncanella* Finley - - Mallory (1959), p. 197, pl. 36, fig. 18a,b,c. - - Mallory (1970), p. 111. - - Vaughan (1976), p. 69. - - Kleinpell and Mallory (1998), p. 234, 237 (list). = *Bulimina truncana* Gumbel - - Smith (1957), p. 175, pl. 24, fig. 11. = *Bulimina whitei* Martin (1943), p. 20, pl. 6, fig. 5a,b. - - Smith (1957), p. 175-176, pl. 24, fig. 9. - - Mallory (1959), p. 198, pl. 28, fig. 18a, b, c; pl. 36, fig. 19a, b, c. - - Mallory (1970), p. 111, pl. 7, fig. 5a, b. - - Vaughan (1976), p. 69. - - Berggren and Aubert (1983), pl. 3, figs. 11-12. - - Browning and others (1998), p. 143, 150 (list).

**Range:** The species *B. alazaensis* was assigned a variety of names in California strata and most are either junior synonyms or misidentifications. The range of *B. alazaensis* is given as earliest Eocene (P6b) to

the Oligocene (P22) (Tjalsma and Lohmann, 1983). This range spans the ranges given by Mallory (1959) for *B. adamsi* (late Penutian through late Ulatisian), *B. corrugata* (early Ulatisian through late Narizian), *B. truncanella* (late Ynezian through late Narizian), and *B. whitei* (early Bulitian through early Narizian). No Ynezian or Bulitian occurrences appear in the reexamined sections. The oldest occurrence is in the Media Agua Creek section where *B. alazaensis* occurs in the mixed assemblage between the Ynezian and the Penutian Stage (fig. 4.8). Almgren and others (1988) give the range of *B. corrugata* as pseudo-C through A-2 zones, which is equivalent to nannofossil zones CP11 through CP14b (planktic foraminiferal zones late P8-P14).

**Ecology:** Along the East Pacific margin, *B. corrugata* and *B. whitei* have upper depth limits in the lower middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980).

*Bulimina bradburyi* Martin (1943), p. 19, pl. 6, fig. 4a, b. - - Mallory (1959), p. 188, pl. 16, fig. 11. - - Mallory (1970), p. 104. - - Gibson (1976), Table 2 (list). - - Tjalsma and Lohmann (1983), p. 24, pl. 12, figs. 1, 2a, b. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 140, 143 (list). - - Mallory and others (1998), p. 255 (list). = *Buliminella bradburyi* (Martin) - - Berggren and Aubert (1983), pl. 2, fig. 13. = *Bulimina* cf. *B. bradburyi* Martin - - Kleinpell and Mallory (1998), p. 234 (list).

**Comments:** Confusion exists between *Bulimina excavata* and *B. bradburyi*, which are approximately the same size and shape. *B. excavata* has a small depression along the suture lines that extends upward into the chambers, usually one per chamber. The specimen illustrated by Mallory (1959), pl. 16, fig. 13) as *B. excavata* may be *B. bradburyi* but preservation obscures the presence or absence of excavations. *Bulimina bradburyi* is morphologically close to *B. tuxapamensis* from which it differs by having a more slender test, somewhat inflated chambers, and a generally smaller size (Tjalsma and Lohmann, 1983).

**Range:** *Bulimina bradburyi* ranges from the late Paleocene (P4) into the early Oligocene (P22) (Tjalsma and Lohmann, 1983). Mallory (1959) gives the range as late Ynezian to early Penutian. The late Ynezian and Bulitian occurrences are from the Media Agua Creek (fig. 4.8), Arroyo el Bulito (fig. 4.7), and Simi Valley sections in strata assigned to planktic foraminiferal zones P4 through P7 (Poore, 1976; Filewicz and Hill, 1983; Heitman, 1983), and thus are within the range given for this cosmopolitan species.

**Ecology:** Along the East Pacific margin, *B. bradburyi*

has an upper depth limit in upper bathyal biofacies (150 to 500 m) (Ingle, 1980).

*Bulimina callahani* Galloway and Morrey. - - Martin (1943), p. 9 (list). - - Mallory (1959), p. 188, pl. 16, fig. 10. - - Mallory (1970), p. 104. - - Berggren and Aubert (1983), pl. 3, figs. 1-5. - - Tjalsma and Lohmann (1983), p. 24-25, pl. 11, figs. 6a-7c. - - van Morkhoven and others (1986), p. 322-327, pl. 105A, figs. 1-3; pl. 105B, figs. 1-4. - - Browning and others (1998), p. 143 (list).

**Range:** *Bulimina callahani* ranges from the late Paleocene (P6a) through middle Eocene (P10) (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986). Mallory (1959) gives the range as late Ynezian through early Ulatisian. These occurrences are in strata assigned to planktic foraminiferal zones P6b through P10. A single rare occurrence in the Paleocene (P4) of the Simi Valley section is, however, noted and in the same sample as a rare occurrence of *Pullenia eocenica* whose presence in the Paleocene is also questioned.

**Ecology:** *Bulimina callahani* is a middle and lower bathyal and abyssal species (van Morkhoven and others, 1986). Its upper depth limit is estimated as 600 m along the Pacific margin (Berggren and Aubert, 1983). Ingle (1980) places the upper depth limit of this species in upper middle bathyal biofacies (500 to 1,500 m).

*Bulimina excavata* Cushman and Parker - - Mallory (1959), p. 190, pl. 16, fig. 13. - - Mallory (1970), p. 106. - - Gibson (1976), Table 2 (list). - - Almgren and others (1988), fig. 5 (list). - - Browning and others (1998), p. 143 (list).

**Range:** Mallory (1959) gives the range as upper Ynezian through lower Bulitian based on the occurrence of this species in the Simi Valley, Arroyo el Bulito, and Reliz Canyon sections. Each of these occurrences is in the Ynezian Stage coeval with P4 to P5 and CP7 to CP8 as determined by this study (figs. 4.7 and 4.13). In the Media Agua Creek section, *B. excavata* is recognized at the base of the Penutian interval in strata assigned to zones P6b and CP9 (fig. 4.8). Almgren and others (1988) restrict this species to their C zone or modified Penutian Stage, which is equivalent to nannofossil zones CP9 through CP10 (planktic foraminiferal zones P7 to P8). Confusion between *B. excavata* and *B. bradburyi* is unresolved at this time.

*Bulimina macilenta* Cushman and Parker - - Mallory (1959), p. 193-194, pl. 28, fig. 15a,b,c. - - Mallory (1970), p. 108. - - Berggren and Aubert (1983), pl. 3, fig. 8. - - Tjalsma and Lohmann (1983), p. 25, pl.

14, fig. 3. - - Kleinpell and Mallory (1998), p. 234 (list). - - Mallory and others (1998), p. 258 (list). - - Browning and others (1998), p. 143, 150 (list). = *Bulimina arkandelpiana macilenta* Cushman and Parker - - Heitman (1983), fig. 4 (list). = *Bulimina pachecoensis* Smith (1957), p. 175, pl. 24, fig. 14.

**Range:** *Bulimina macilenta* ranges from zones P7 through P15 (Tjalsma and Lohmann, 1983). Mallory (1959) gives the range as late Ynezian through early Narizian. The Ynezian and Bulitian occurrences are in the Media Agua Creek, Arroyo el Bulito and Simi Valley sections. In the Media Agua Creek section the Ynezian occurrence is now assigned to the Penutian, P7 zone and in the Arroyo el Bulito section, the Bulitian occurrence is now assigned to the early Eocene, Penutian, coeval with CP11. In the Simi Valley section *B. macilenta* occurs in strata assigned to the Ynezian through Bulitian Stages coeval with zones P4 to P5 and CP5 through CP8. These specimens have probably been misidentified, as these occurrences are considerably older than the range of this species noted globally. The range of *B. macilenta* in California is therefore the same as the cosmopolitan range.

**Ecology:** Along the East Pacific margin, *B. macilenta* has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980).

*Bulimina microcostata* Cushman and Parker - - Mallory (1959), p. 194, pl. 16, fig. 9. - - Kleinpell and Mallory (1998), p. 237 (list).

**Range:** *Bulimina microcostata* is restricted to the Narizian (Mallory, 1959). In this study *B. microcostata* was found only in the Devils Den section, where it occurs in Narizian strata correlated with Chrons C19n or C20n. The range is therefore tentatively given as late P12 through P15.

**Ecology:** Along the East Pacific margin, *B. microcostata* has an upper depth limit in the upper middle bathyal biofacies (Ingle, 1980).

*Bulimina sculptilis* Cushman - - Smith (1956), p. 95-96, pl. 12, fig. 9, pl. 5, fig. 4. - - Tipton (1980), p. 265 (list), 274. - - Kleinpell and Mallory (1998), p. 237 (list). = *Bulimina sculptilis lacinata* Cushman and Parker - - Tipton (1980), p. 265 (list), 274.

**Range:** *Bulimina sculptilis* is typically found in late Eocene strata throughout California. In this study it occurs in the Narizian and Refugian of the Devils Den and Arroyo el Bulito sections, and Seaboard Welch Well #1 (figs. 4.10, 4.11, and 4.12) coeval with zones P15 through P16.

*Bulimina semicostata* Nuttall - - Vaughan (1976), p. 69. - - Tjalsma and Lohmann (1983), p. 25, pl. 13,

figs. 1-3. - - van Morkhoven and others (1986), p. 279-281, pl. 93, figs. 1-5. - - Browning and others (1998), p. 143 (list). = *Bulimina* cf. *B. semicostata* (Nuttall) - - Mallory (1970), p. 110, pl. 7, fig. 3a,b. - - Mallory and others (1998), p. 257 (list). = *Bulimina semicostata lacrima* Mallory (1959), p. 196, pl. 16, fig. 8a, b, c. - - Mallory (1970), p. 110. - - Kleinpell and Mallory (1998), p. 234 (list). = *Bulimina lacrima* Mallory - - Mallory and others (1998), p. 257 (list).

**Range:** *Bulimina semicostata* ranges from the early Eocene (P6b) through early Oligocene (P18) (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986). Mallory (1959) gave the range as early Ulatisian through early Narizian, which is consistent with the cosmopolitan range of this species. In the present study, specimens identified as *B. semicostata* were found in the Ynezian portion of the Simi Valley section, occurring in the same interval as several other seemingly out of place early Eocene species (fig. 4.13). In the Media Agua Creek and Arroyo el Bulito sections, *B. semicostata* ranges from Penutian through Narizian, coeval with P8 through P10.

**Ecology:** Although *B. semicostata* is primarily a lower bathyal and abyssal species, it has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980; van Morkhoven and others, 1986).

*Bulimina trinitatensis* Cushman and Jarvis - - Tjalsma and Lohmann (1983), p. 7-8. - - Berggren and Aubert (1983), pl. 3, figs. 9, 10. - - van Morkhoven and others (1986), p. 299-303, pl. 98a, figs. 1-2; pl. 98B, figs. 1-4. - - Browning and others (1998), p. 140, 143 (list).

**Range:** *Bulimina trinitatensis* ranges from the early Paleocene (P1) through late Eocene (P16) (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986). This species is not recognized in Mallory's (1959) work but has been recognized in the Simi Valley and Pacheco Syncline sections.

**Ecology:** *Bulimina trinitatensis* is primarily a bathyal to abyssal species (van Morkhoven and others, 1986). During the Eocene the upper depth limit may have been as shallow as 500 to 600 m (Barr and Berggren, 1981; Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986).

*Bulimina tuxapamensis* Cole - - Tjalsma and Lohmann (1983), p. 26, pl. 12, figs. 3-4. - - van Morkhoven and others (1986), p. 155-158, pl. 51A, figs. 1-4; pl. 51B, figs. 1-2. - - Mallory and others (1998), p. 255 (list). - - Mallory and others (1998), p. 257, 258 (list). = *Buliminella bradburyi* (Martin) - - Berggren

and Aubert (1983), p. 16, pl. 2, fig. 13. = *Uvigerina* cf. *lodoensis* (Martin) - - Smith (1957), p. 178, pl. 25, fig. 7.

**Range:** *Bulimina tuxapamensis* ranges from the late Paleocene (P6a) through early middle Miocene (N9) with doubtful occurrences in middle Miocene zones N10 to N13 (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986). Mallory (1959) did not recognize this species in his sections. It was identified in the Arroyo el Bulito and Pacheco Syncline sections in the Penutian Stage coeval with zones CP10 and CP11.

**Ecology:** *Bulimina tuxapamensis* is a bathyal to abyssal species that occurs commonly in the upper bathyal biofacies (van Morkhoven and others, 1986). Ingle (1980) indicates the upper depth limit of *B. bradburyi* is in the upper bathyal biofacies (150 to 500 m).

*Buliminella grata* Parker and Bermudez. - - Gibson (1976), Table 2 (list). - - van Morkhoven and others (1986), p. 163-165, p. 54, figs. 1-2. - - Mallory and others (1998), p. 257 (list). = *Buliminella grata* Parker and Bermudez *convoluta* Mallory (1959), p. 185, pl. 15, fig. 13. - - Berggren and Aubert (1983), pl. 2, figs. 11, 12. - - Kleinpell and Mallory (1998), p. 234 (list). = *Buliminella grata joaquinensis* Mallory (1959), p. 185, pl. 15, fig. 13. - - Mallory (1970), p. 103, pl. 6, fig. 6. - - Mallory and others (1998), p. 258 (list).

**Comments:** *Buliminella obtusa* (d'Orbigny) in Mallory and others (1998, list) may be a synonym of *B. grata*; further checking is needed.

**Range:** An early Paleocene (P1) through middle Miocene (N12) range is given by van Morkhoven and others (1986). Mallory (1959) indicates that this species ranges from Ulatisian through Narizian. Its presence in the Ynezian through Penutian of the Arroyo el Bulito section represents the older portion of the *B. grata* range.

**Ecology:** *Buliminella grata* is primarily a bathyal species; maximum abundances occurred at depths of 1,000 to 2,000 m in the Atlantic (Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986).

*Buliminella robertsi* Howe and Ellis - - Mallory and others (1998), p. 255 (list). = *Buliminella grata* Parker and Bermudez - - Smith (1957), p. 173, pl. 24, fig. 10. - - Mallory (1959), p. 186, pl. 15, fig. 14. - - Mallory (1970), p. 103. - - Kleinpell and Mallory (1998), p. 234 (list). - - Browning and others (1998), p. 150 (list). = *Turrilina robertsi* (Howe and Ellis) - - Tjalsma and Lohmann (1983), p. 37, pl. 14, fig. 5.

**Comments:** *Buliminella robertsi* is probably a junior

synonym of *Turrilina brevispira*.

**Range:** *Buliminella robertsi* ranges from latest Paleocene (P6a) through late Eocene (P15) (Tjalsma and Lohmann, 1983). Mallory (1959) gives the range as Ynezian through Narizian. Ynezian and Bulitian occurrences in the Media Agua, Simi Valley, Pacheco Syncline, and Devils Den (Mallory, 1959) sections are now assigned to the Penutian through Ulatisian (fig. 4.8) within the cosmopolitan range of this species.

**Ecology:** Along the East Pacific margin, *B. robertsi* has an upper depth limit on the outer shelf (Ingle, 1980).

*Cassidulina galvinensis* Cushman and Frizzell - - Smith (1956), p. 99-100, pl. 13, fig. 11. - - Tipton (1980), p. 274.

**Range:** *Cassidulina galvinensis* ranges from the late Refugian into the early Zemorrian. The range of this species is considered to be P16 through P20, however confusion between *C. galvinensis* and *C. crassipunctata* in California needs to be resolved.

*Caucasina schencki* (Beck) = *Bulimina schencki* Beck - - Kleinpell and Mallory (1998), p. 234 (list). - - Tipton (1980), p. 265 (list), 274. = *Bulimina capitata* Yokoyama - - Smith (1956), p. 95, pl. 13, fig. 5.

**Range:** *Caucasina schencki* first appears in the Narizian and ranges through the Refugian in the Devils Den, Arroyo el Bulito, and Seaboard Welch Well #1 sections examined for this study. The range of this species is tentatively given as P15 through P17.

*Cibicides haydoni* (Cushman and Schenck) - - McDougall (1980), p. 34. - - Tipton (1980), p. 265, (list), 274. = *Planulina haydoni* Cushman and Schenck - - Smith (1956), p. 100, pl. 16, fig. 5.

**Range:** Both McDougall (1980) and Tipton (1980) restrict this species to the Refugian Stage coeval with planktic foraminiferal zones P15 and P16.

**Ecology:** *Cibicides haydoni* has an upper depth limit in the outer shelf biofacies (Ingle, 1980).

*Cibicides martinezensis* Cushman and Barksdale - - Martin (1943), p. 9 (list). - - Smith (1957), p. 193, pl. 31, fig. 6. - - Mallory (1959), p. 267, pl. 35, fig. 7a-c; pl. 38, fig. 7a-c. - - Mallory (1970), p. 159. - - Vaughan (1976), p. 70. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 143 (list). - - Kleinpell and Mallory (1998), p. 234 (list). = *Cibicides* cf. *C. martinezensis* Cushman and Barksdale - - Almgren and others (1988), fig. 5 (list). = *Cibicidoides martinezensis malloryi* Smith (1957), p. 193-194, pl. 31, fig. 7. - - Mallory (1970), p. 159.

**Range:** Mallory (1959) gives the range as Bulitian to lower Narizian with questionable occurrences in

the upper Ynezian. The upper Ynezian occurrences are in Lodo Gulch (Martin, 1943) and Media Agua Creek (Mallory, 1959). These occurrences are in strata now assigned to the Penutian and Ulatisian Stages coeval with zones P6b through P10 (fig. 4.8). The Paleocene occurrences in the Simi Valley section may be attributed to taxonomic problems, as all other occurrences of this species are restricted to the Eocene. In the Simi Valley, specimens assigned to *C. martinezensis* may instead be *C. alleni*, which is a Paleocene species. Almgren and others (1988) also give the range of this species as zones C through A-2 (rare), which is coeval with nannofossil zones CP9 through CP14 (planktic foraminiferal zones P6b to P14).

*Cibicidoides alleni* (Plummer) - - Heitman (1983), fig. 4 (list). = *Cibicides martinezensis* Cushman and Barksdale - - Martin (1943), p. 9 (list). = *Cibicides spiropunctatus* (Gumbel). - - Browning and others (1998), p. 140, 143 (list). = *Cibicides* aff. *C. spiropunctatus* (Gumbel) - - Browning and others (1998), p. 143 (list).

**Range:** van Morkhoven and others (1986) indicate the range of *C. alleni* is P1 to P6b and that this species is the ancestor of the *C. eoceanus-tuxpamensis* lineage. Although Mallory (1959) does not recognize this species in California strata, it has been recognized in the Ynezian of the Simi Valley and Pacheco Syncline sections (Heitman, 1983; McDougall, unpublished paleontology reports; fig. 4.13). Specimens assigned to *Cibicides spiropunctatus* by Browning and others (1998) are probably this species.

**Ecology:** The bathymetric range of *C. alleni* is middle neritic to middle bathyal in the Paleocene (P1 to P5) and is restricted to the middle and outer neritic in the late Paleocene and early Eocene (P6a to P6b) (van Morkhoven and others, 1986).

*Cibicidoides coalingensis* (Cushman and Hanna) - - Smith (1957), p. 195, pl. 30, figs. 2, 3. - - Vaughan (1976), p. 70. - - Tipton (1980), p. 274. = "*Anomalina*" *coalingensis* Cushman and Hanna - - Martin (1943), p. 9 (list). = *Anomalina coalingensis* (Cushman and Hanna) - - Boyd (1998), p. 123, 124 (list). = *Cibicides coalingensis* (Cushman and Hanna) - - Almgren and others (1988), fig. 5 (list). = *Cibicidoides coalingensis* (Cushman and Hanna) - - Mallory (1959), p. 273, pl. 38, fig. 11a-c. - - Mallory (1970), p. 162. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 143, 150 (list). - - Kleinpell and Mallory (1998), p. 238 (list).

**Range:** Mallory (1959) gives the range of *C. coalingensis* as lower Bulitian through upper Narizian,

and Almgren and others (1988) give the range as restricted to zone B-1 equivalent to nannofossil zones CP11 to CP12a (late P9 to early P10). Bulitian occurrences from the Media Agua Creek section are in the interval now assigned to the Penutian (fig. 4.8). In the Simi Valley section, *C. coalingensis* occurs in the Bulitian interval but because of taxonomic problems in this section this species may not be correctly identified. Additionally this species occurs in the Penutian through Refugian Stages in the Pacheco Syncline, Vaca Valley, and Devils Den sections examined in this study; this range is much broader than indicated by Almgren and others (1988). The range of *C. coalingensis* is tentatively given as P6b through P17.

**Ecology:** The upper depth limit of *C. coalingensis* is given as both outer shelf and lower middle bathyal biofacies by Ingle (1980).

*Cibicidoides dayi* (White) = *Cibicides stephensoni* Cushman -- Mallory (1959), p. 271, pl. 32, fig. 9. -- Browning and others (1998), p. 143 (list).

**Range:** *Cibicidoides dayi* ranges from Late Cretaceous (Campanian) through late Paleocene (P5) (van Morkhoven and others, 1986). Mallory (1959) recognized this species in the Ynezian of the California sections and it is noted in the Ynezian of the Simi Valley and Pacheco Syncline sections as well as the Lodo Gulch section.

**Ecology:** *C. dayi* is a bathyal and abyssal species (van Morkhoven and others, 1986).

*Cibicidoides eocaenus* (Gumbel) -- van Morkhoven and others (1986), p. 256-263, pl. 86A, figs. 1-4; pl. 86B, figs. 1-2; pl. 86C, figs. 1-3; pl. 86D, figs. 1-2. = *Cibicides spiropunctatus* Galloway and Morrey -- Mallory (1959), p. 270, pl. 25, fig. 3. -- Gibson (1976), Table 2 (list) = *Cibicides whitei* Martin (1943), p. 122, pl. 8, figs. 4a, b, c. -- Vaughan (1976), p. 70. = *Cibicidoides whitei* (Martin) -- Berggren and Aubert (1983), p. 10 (list), p. 16 (list).

**Range:** *Cibicidoides eocaenus* ranges from the early Eocene (P6b) through late Oligocene (P22) (van Morkhoven and others, 1986). Mallory (1959) noted *C. spiropunctatus* and *C. whitei* in the Ynezian through Narizian. The Ynezian and Bulitian occurrences noted by Mallory (1959) are in Media Agua Creek and Lodo Gulch; both occurrences are now assigned to the Penutian (fig. 4.8).

**Ecology:** *Cibicidoides eocaenus* is primarily a bathyal species although it ranges from outer neritic to abyssal depths. Ingle (1980) considered the upper depth limit of *C. perlucidus* to be in the lower middle bathyal and of *C. spiropunctatus* to be in the upper bathyal biofacies.

*Cibicidoides fortunatus* (Martin) = *Cibicides fortunatus* Martin (1943), p. 31, pl. 8, fig. 5a, b, c. -- Mallory (1959), p. 265, pl. 24, fig. 1. -- Mallory (1970), p. 158. -- McDougall (1980), pl. 24, figs. 10-11. -- Berggren and Aubert (1983), pl. 5, figs. 22-24.

**Range:** *Cibicidoides fortunatus* is probably a junior synonym or ecological variant of *C. subspiratus*, which ranges from P6b through P9 (van Morkhoven and others, 1986). Mallory (1959) gave the range of *C. fortunatus* as late Ynezian to late Penutian. The late Ynezian occurrences in the Media Agua Creek section where *Cibicidoides fortunatus* ranges from samples A7078 to A7076 are now assigned to zone P6b (fig. 4.8). The upper Bulitian occurrence is from Lodo Gulch in strata now assigned to planktic foraminiferal zone P7 and younger (Poore, 1976; Berggren and Aubert, 1983).

**Ecology:** Along the East Pacific margin, *C. fortunatus* has an upper depth limit in the upper bathyal biofacies (Ingle, 1980).

*Cibicidoides grimsdalei* (Nuttall) -- Berggren and Aubert (1983), pl. 5, figs. 19, 20, 21. -- van Morkhoven and others (1986), p. 247-251, pl. 83a, figs. 1-3; pl. 83b, figs. 1-7. = ?*Cibicides laimingi* of Mallory (1959), pl. 24, fig. 3.

**Range:** An early Eocene (P8) through Miocene (N4) range is given by van Morkhoven and others (1986). *Cibicides laimingi* was reported by Mallory (1959) to range from lower Ulatisian through lower Narizian Stages in California. In sections examined for this study *C. grimsdalei* is present in the Devils Den section (fig. 4.10) where it occurs in the Narizian well within the range of this species.

**Ecology:** *Cibicidoides grimsdalei* was a lower bathyal and abyssal species. Ingle (1980) gives the upper depth limit of this species along the Pacific margin as in the lower bathyal biofacies. Greatest abundances of this species are reported at paleodepths of 2,000 to 4,000 m in the Atlantic by Tjalsma and Lohmann (1983).

*Cibicidoides praemundulus* Berggren and Edwards = *Cibicides ungerianus* (d'Orbigny) -- Tjalsma and Lohmann (1983), p. 28-29, pl. 18, fig. 1; pl. 21, figs. 5-6. = *Cibicides* cf. *C. ungerianus* (d'Orbigny) -- Almgren and others (1988), fig. 5 (list). Probably not *Cibicides* cf. *C. ungeriana* (d'Orbigny) -- Mallory (1959), p. 272. -- Mallory (1970), p. 160, pl. 15, fig. 3a, b, c.

**Range:** An early Eocene (P6b) through late Oligocene (P22) range is given by van Morkhoven and others (1986). Almgren and others (1988) restrict this species to zone D, which is equivalent to nannofossil zone CP9 and planktic foraminiferal zone P6b. This

species is present in the Pacheco Syncline in the Penutian (CP10) interval. As this species becomes more widely recognized, a better understanding of its range will emerge.

**Ecology:** *Cibicidoides praemundulus* is primarily a lower bathyal and abyssal form, but occurs sporadically in middle bathyal sediments. Greatest abundances are found at abyssal depths (van Morkhoven and others, 1986).

*Cibicidoides subspiratus* (Nuttall) - - van Morkhoven and others (1986), p. 314-316, pl. 102, figs. 1a,b,c.

**Range:** A late early Eocene (P9) through late middle Eocene (P13) range is given by van Morkhoven and others (1986). This species was not recognized in California strata by Mallory (1959). It is included because of its association with *C. fortunatus* and because it has been found in California although not in the sections examined for the current study.

**Ecology:** *Cibicidoides subspiralis* is a bathyal and abyssal species (van Morkhoven and others, 1986).

*Clavulina anglica* (Cushman) = *Pseudoclavulina anglica* Cushman (1936), p. 18, pl. 3, fig. 5.

**Range:** This species was not previously recognized in California, which may be the result of lumping this species with another genus such as *Karrerella* or because the species was not recorded. King (1989) observes *C. anglica* in North Sea sediments in the early Paleocene to early Eocene, zones NSB 1a to 1b and 3a to 3b. These zones are equivalent to planktic foraminiferal zones P1 to early P4 and late P6b to early P9. Jenkins and Murray (1989) and Bragg and others (1975) also observe this species in the early Eocene and report rare occurrences as young as P14 in Italy.

**Ecology:** *Clavulina anglica* is common on marine shelves (Murray and others, 1989).

*Coryphostoma incrassata* (Reuss) - - van Morkhoven and others (1986), p. 382-384, pl. 126.

**Range:** *Coryphostoma incrassata* is a Late Cretaceous species (van Morkhoven and others, 1986). *Bolivina incrassata* recognized by Mallory in California strata is *C. midwayensis*, a Tertiary species.

**Ecology:** The upper depth limit of *C. incrassata* is on the outer shelf (van Morkhoven and others, 1986).

*Coryphostoma midwayensis* - - van Morkhoven and others (1986), p. 364-366, pl. 118, figs. 1a-c. = *Bolivina incrassata* Reuss - - Goudkoff (1945), Table II. - - Mallory (1959), p. 201, pl. 16, fig. 24. - - Mallory (1970), p. 113. - - Heitman (1983), fig. 4 (list). = *Bolivina midwayensis* Cushman - - Mallory (1959), p. 202. - - Gibson (1976), Table 2 (list). - -

Browning and others (1998), p. 143 (list).

**Range:** *Coryphostoma midwayensis* ranges from the Late Cretaceous (Maastrichtian) to early Paleocene (P5) (van Morkhoven and others, 1986). Mallory (1959) reports a single occurrence of *B. incrassata* from the upper Bulitian of the Media Agua Creek section (sample A-7069) that is early Eocene, zone P7 (Poore, 1976); this species was not listed by Mallory (1970). *Coryphostoma midwayensis* occurs in the Cheneyian Stage (Goudkoff, 1945) and the Ynezian in the Arroyo el Bulito and Simi Valley sections (figs. 4.8 and 4.9).

**Ecology:** *Coryphostoma midwayensis* is primarily an outer neritic and bathyal species and is very rare in abyssal deposits (van Morkhoven and others, 1986).

*Eggerella elongata* Blaisdell - - Smith (1971), p. 34, pl. 2, fig. 5. - - Tipton (1980), p. 274. = *Eggerella* sp. Mallory (1959), p. 124. - - Mallory (1970), p. 44-45. - - Berggren and Aubert (1983), p. 11 (list).

**Range:** Mallory (1959) gives the range of *E. elongata* as upper Ulatisian through upper Narizian. *E. elongata* is present in the Ulatisian and (or) Narizian intervals of the Media Agua Creek and Pacheco Syncline sections as well as many other Narizian and Refugian sections in California. The range of *E. elongata* s.s. is late Ulatisian through Refugian, coeval with zones P12 to P16. Questionable occurrences of *E. elongata* are found in strata as old as early Ulatisian, coeval with zone P10.

*Eponides mexicanus* (Cushman) - - Smith (1957), p. 182, pl. 27, fig. 10. - - Mallory (1959), p. 237, pl. 37, fig. 11; pl. 41, fig. 9. - - Vaughan (1976), p. 73. - - Heitman (1983), fig. 4 (list). - - Boyd (1998), p. 122, 124, 125 (list). - - Browning and others (1998), p. 150 (list). = *Eponides* aff. *E. mexicana* (Cushman) - - Smith (1957), p. 183, pl. 27, fig. 15. = *Eponides gaviotaensis* Wilson - - Smith (1956), p. 98, pl. 14, fig. 8. - - Tipton (1980), p. 265 (list), 274. = *Eponides guaybalensis yeguaensis* Weinzierl and Applin - - Heitman (1983), fig. 4 (list). = *Eponides yeguaensis* Weinzierl and Applin - - Tipton (1980), p. 274. = *Eponides kleinPELLI* Cushman and Frizzell - - Tipton (1980), p. 265 (list), 274. = *Neoeponides mexicanus* (Cushman) - - Mallory (1970), p. 134.

**Range:** *Eponides mexicanus* is a long ranging species that is common throughout the Eocene and Oligocene. It is present in most sections examined for this study but occurs under a wide variety of names. The range of *E. mexicanus* s.s. is P7 through P22.

**Ecology:** *Eponides mexicanus* has an upper depth limit in the inner neritic (0 to 50 m) (Ingle, 1980).

*Eponides plummerae* Cushman - - Mallory (1959), p.

25, 32, 86 (not in taxonomic section). -- Gibson (1976), Table 2 (list). -- Heitman (1983), fig. 4 (list). -- Browning and others (1998), p. 145 (list).

**Range:** *Eponides plummerae* was given a range of Ynezian and Bulitian (Mallory, 1959). In the sections examined for this study *E. plummerae* occurs in the Ynezian and Bulitian in the Arroyo el Bulito, Simi Valley and Lodo Gulch sections. The range of this species in California is tentatively given as P3 through P5, but it probably has a more extensive range.

*Frondicularia frankei* Cushman -- Mallory (1959), p. 160. = ? *Frondicularia* cf. *F. inversa* -- Smith (1957), p. 169, pl. 23, fig. 8. -- Mallory (1959), p. 160. -- Mallory and others (1998), p. 256 (list).

**Range:** *Frondicularia frankei* is an E zone marker of Laiming (1940) but is not listed by Mallory (1959). *Frondicularia frankei* is recognized in the Ynezian of several sections examined for this study (Arroyo el Bulito, fig. 4.7; Pacheco Syncline, fig. 4.14). Several other species of *Frondicularia* that also occur in the Ynezian and Bulitian of California may be synonyms. The range of this species is tentatively given as P4.

*Globocassidulina globosa* (Hantken) -- Tipton (1980), p. 265 (list), 274. = *Cassidulina globosa* Hantken -- Smith (1956), p. 100, pl. 14, fig. 2. -- Smith (1957), p. 187, pl. 28, fig. 13. -- Mallory (1959), p. 226, pl. 33, fig. 11a,b. -- Mallory (1970), p. 139. = *Cassidulina* cf. *C. globosa* -- Mallory (1970), p. 140. = *Globocassidulina subglobosa* (Brady) -- Vaughan (1976), p. 70. -- Tjalsma and Lohmann (1983), p. 31, pl. 16, fig. 9. -- Berggren and Aubert (1983), pl. 4, fig. 15, 16, 17. -- Kleinpell and Mallory (1998), p. 235, 238 (list).

**Range:** *Globocassidulina globosa* is a common species in California, where it ranges from the early Penutian through late Narizian (Mallory, 1959) and into the Refugian (Tipton, 1980). Tjalsma and Lohmann (1983) indicate that this species first appears in the Paleocene planktic zone P4 and ranges throughout the Eocene and into younger strata. No Paleocene occurrences have been noted yet in California. *Globocassidulina globosa* is found in the Penutian through Ulatisian of the Media Agua Creek section (P7 through at least P10).

**Ecology:** Along the East Pacific margin, the upper depth limit of *G. globosa* is in the outer shelf biofacies (50 to 150 m) (Ingle, 1980).

*Glomospira gordialis* (Jones and Parker) = *Glomospira charoides* (Jones and Parker) *corona* Cushman and Jarvis -- Mallory (1959), p. 109, pl. 1, fig. 16. -- Mallory (1970), p. 28-29. -- Gibson (1976), Table 2

(list). -- Kleinpell and Mallory (1998), p. 235 (list). = *Glomospira corona* Cushman and Jarvis -- Mallory and others (1998), p. 256 (list).

**Range:** *Glomospira gordialis* ranges from planktic foraminiferal zone P4 (late Paleocene) to P7 (early Eocene) (Kaminski and others, 1988). Mallory (1959) notes this species primarily in the Paleocene but also notes its presence in the Ulatisian and Narizian of Media Agua Creek and Devils Den sections. In the Media Agua Creek section, *G. gordialis* ranges from the Ynezian through the Penutian (P4 to early P9); it is not present in the Ulatisian (fig. 4.8). This species is recognized in the Narizian of the Devils Den section (Kleinpell and Mallory, 1998), but until further examination this young occurrence is questioned.

*Gonatosphaera eocenica* Mallory (1959), p. 225, pl. 18, fig. 19. -- Mallory (1970), p. 124, pl. 9, fig. 2. -- Mallory and others (1998), p. 258 (list). = *Gonatosphaera multicosta* Laiming (1940), (not Costa), p. 550, (list).

**Range:** *Gonatosphaera eocenica* occurs rarely in the early Penutian through early Ulatisian (Mallory, 1959). *Gonatosphaera eocenica* is present in the Media Agua Creek section in benthic foraminiferal assemblages assigned to the Penutian Stage by McDougall (1988, 1991) and with planktic foraminifers assigned to zone P8 (Poore, 1980). In the Arroyo el Bulito and Pacheco Syncline sections, *G. eocenica* occurs with benthic foraminiferal assemblages interpreted as Penutian (figs. 4.7 and 4.14) and in association with nannofossils assigned to zone CP10/CP11 (Poore, 1976; Bukry, unpublished paleontologic report, 1988). Although the range appears to be restricted to the Penutian (zones P7 to early P9), occurrences in the Ulatisian Stage have not yet been ruled out.

*Gyroidinoides globosus* (Hagenow) -- Tjalsma and Lohmann (1983), p. 14, pl. 7, fig. 5. -- van Morkhoven and others (1986), p. 329-331, pl. 107, figs. 1-3. = *Gyroidina globosa* (Hagenow) -- Goudkoff (1945), Table II. = *Gyroidina* cf. *G. globosa* (Hagenow) -- Heitman (1983), fig. 4 (list). -- Browning and others (1998), p. 145 (list).

**Comments:** *Gyroidina obesa* and *G. depressa* in Mallory and others (1998) and Goudkoff (1945) are probably synonymous with *Gyroidinoides globosus*.

**Range:** *Gyroidinoides globosus* ranges from the Cretaceous (Campanian) through the early Eocene P6b zone (van Morkhoven and others, 1986). Although this species was not recognized by Mallory (1959) in California strata, it was noted in the Ynezian of the Simi Valley section (Heitman, 1983; Browning

and others, 1998), where it occurs in the Ynezian Stage coeval with zones P4 and CP5 through CP8 (fig. 4.13).

**Ecology:** *Gyroidina globosus* is an upper bathyal and abyssal species (van Morkhoven and others, 1986).

*Hanzawaia ammophila* (Gumbel) - - van Morkhoven and others (1986), p. 168-171, pl. 56, figs. 1-3. = *Cibicides cushmani* Nuttall - - Smith (1957), p. 192, pl. 31, fig. 4. - - Mallory (1959), p. 264, pl. 31, fig. 3. - - Mallory (1970), p. 158. - - Tipton (1980), p. 265 (list), 274. = *Cibicidina cushmani* (Nuttall) - - Kleinpell and Mallory (1998), p. 234 (list). = *Hanzawaia cushmani* (Nuttall) - - Tjalsma and Lohmann (1983), p. 32, pl. 17, fig. 1. = *Anomalina sampsoni* Mallory (1959), p. 262, pl. 23, fig. 7. - - Mallory (1970), p. 154, pl. 14, fig. 6.

**Range:** A range of latest Paleocene (P6a) through middle Miocene (N11) is given by van Morkhoven and others (1986) for *H. ammophila*. The form frequently assigned to *H. cushmani* is most commonly found in the Eocene (P6a) to Oligocene (P18). Mallory (1959) gave the range as late Bulitian through late Narizian, however the Bulitian occurrence in the Media Agua Creek section is actually in the Penutian (P7), so the range in Media Agua Creek is Penutian through Ulatisian (P7 through at least P10) (fig. 4.8). In this study, *H. ammophila* occurs in the Devils Den, Arroyo el Bulito, and Seaboard Welch Well #1 sections.

**Ecology:** The depth range of *H. ammophila* is outer neritic to upper bathyal; it may also be found at abyssal depths (van Morkhoven and others, 1986). Ingle (1980) gives the upper depth limit of this species along the Pacific margin as in the lower middle bathyal biofacies (1,500 to 2,000 m).

*Hanzawaia caribaea* (Cushman and Bermudez) - - van Morkhoven and others (1986), p. 303-305, pl. 99, figs. 1-2. = *Anomalina crassisepta* Cushman and Siegfus - - Mallory (1959), p. 258, pl. 32, fig. 4. - - Mallory (1970), p. 152. - - Vaughan (1976), p. 67. - - Mallory and others (1998), p. 258 (list). - - Kleinpell and Mallory (1998), p. 234 (list). = *Anomalinoides crassisepta* (Cushman and Siegfus) - - Berggren and Aubert (1983), pl. 5, figs. 4-6.

**Range:** *Hanzawaia caribaea* ranges from the late early Eocene, zone P9 through middle Eocene zone P13, with questionable occurrences in the late middle Eocene zones P14 to P15 (van Morkhoven and others, 1986). Mallory (1959) considered *A. crassisepta* a long-ranging form that occurred in the late Ynezian through early Narizian strata in the Media Agua Creek section. This species occurs infrequently in the strata now assigned to the Penutian

Stage (fig. 4.8) and becomes more common in the Ulatisian interval. It is also present in the Arroyo el Bulito and the Devils Den sections (Kleinpell and Mallory, 1998; Mallory and others, 1998), where it occurs in the latest Penutian (fig. 4.7) and Narizian (fig. 4.10). The Penutian occurrences of this species suggest that the range should extend at least questionably into older strata (P7 through P8).

**Ecology:** Bathyal species with an upper depth limit of 500 m (Berggren and Aubert, 1983; van Morkhoven and others, 1986).

*Hanzawaia mauricensis* (Howe and Roberts) = *Cibicides* sp. - - Mallory (1959), p. 273, pl. 23, fig. 12. = *Cibicides* spp. - - Mallory (1970), p. 161 (in part). = *Anomalina umbonata* Cushman - - Mallory (1959), p. 262, pl. 31, fig. 2. - - Mallory (1970), p. 155, pl. 14, fig. 4. - - Browning and others (1998), p. 143, 149 (list).

**Range:** Bandy (1949) records *Hanzawaia mauricensis* from the middle Eocene of the Gulf Coast (middle Eocene encompasses zones P9 through P14 and part of P15). In California, *Hanzawaia mauricensis* is present in the Penutian and Ulatisian of the Media Agua Creek section (Bulitian through Narizian of Mallory, 1959, 1970), coeval with zones P7 through at least P10 and in the Bulitian (?) portion of the Simi Valley section. The single specimen in the Simi Valley section occurs in strata assigned to planktic foraminiferal zone P5. The range of this species in California is tentatively given as P7 through P10 but the range will likely be modified as more specimens are identified.

*Karreriella chapapotensis* (Cole) - - Tjalsma and Lohmann (1983), p. 32. = *Karreriella chapapotensis monumentensis* Mallory (1959), p. 126, pl. 5, fig. 3. - - Mallory (1970), p. 47. - - Kleinpell and Mallory (1998), p. 235 (list). = *Karreriella monumentensis* Mallory - - Berggren and Aubert (1983), pl. 1, fig. 16.

**Range:** Tjalsma and Lohmann (1983) give the range of *K. chapapotensis* as early Eocene (P6b) through the Oligocene (P22). The range of the synonym, *K. chapapotensis monumentensis*, is early Ulatisian through early Narizian (Mallory, 1959). In this study *K. chapapotensis* ranges from Ulatisian through the Narizian and is coeval with zones P10 through P11, but only limited younger strata were examined so the cosmopolitan range (P6b to P22) is used.

**Ecology:** Along the East Pacific margin, *Karreriella chapapotensis* has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980).

*Karreriella conversa* (Gryzbowski) - - Kaminski and others (1988), p. 196, pl. 9, figs. 17-18b.

**Range:** *Karreriella conversa* ranges from Late Cretaceous (Maastrichtian) through at least early Eocene (P8) (Kaminski and others, 1988). Gradstein and others (1988) indicate this species ranges into the middle Eocene (approximately 46 Ma, planktic zone P11) in the North Sea.

*Karreriella elongata* Mallory (1959), p. 127, pl. 5, fig. 4.) = *Textularia elongata* (Mallory) - - Vaughan (1976), p. 80.

**Range:** *Karreriella elongata* is probably a junior synonym of *K. subglabra*, which ranges from P8 through Oligocene (Tjalsma and Lohmann, 1983). Mallory (1959) restricts *K. elongata* to the early Narizian, which represents only a portion of the cosmopolitan range. In the sections examined for this study *K. elongata* is present in the Ulatisian (CP12, Vaca Valley, fig. 4.19) and Narizian (Devils Den section, fig. 4.10).

**Ecology:** Along the East Pacific margin, *K. elongata* has an upper depth limit in the lower middle bathyal biofacies (1,500 to 2,000 m) (Ingle, 1980).

*Lenticulina ulatisensis* (Boyd) - - Vaughan (1976), p. 73. - - Berggren and Aubert (1983), pl. 2, fig. 1. = *Robulus ulatisensis* Boyd - - Mallory (1959), p. 142, pl. 6, fig. 10; pl. 40, fig. 4. - - Mallory (1970), p. 62. - - Boyd (1998), p. 122, 123 (list). = *Robulus* cf. *R. ulatisensis* (Boyd) - - Mallory (1970), p. 62.

**Range:** *Lenticulina ulatisensis* ranges from the late Penutian through early Narizian (Mallory, 1959) and is coeval with zones P9 through P12. In this study *L. ulatisensis* is present in the Ulatisian of the Media Agua Creek (fig. 4.8), Pacheco Syncline (fig. 4.14) and Vaca Valley (fig. 4.9) sections. Questionable, poorly preserved specimens from the Penutian of Media Agua Creek were assigned to this species (Mallory, 1959, 1970). The upper limit of this species range may be younger than given here but additional work is needed to verify this.

*Lenticulina welchi* (Church) - - Vaughan (1976), p. 76. - - Tipton (1980), p. 265 (list), 274. - - Kleinpell and Mallory (1998), p. 236, 239 (list). = *Robulus welchi* Church - - Smith (1957), p. 159, pl. 21, figs. 4,5,6. - - Mallory (1959), p. 143, pl. 7, fig. 8. - - Mallory (1970), p. 62-63. = *Robulus* cf. *R. welchi* (Church) - - Smith (1956), p. 89, pl. 10, fig. 6. - - Mallory (1970), p. 63.

**Range:** *Lenticulina welchi* first appears in the Ulatisian and ranges into the late Narizian (Mallory, 1959) and is coeval with zones P10 through P15. In this

study *L. welchi* occurs in the Ulatisian and Narizian of the Media Agua Creek, Simi Valley, Vaca Valley, Devils Den, and Refugian sections. In Media Agua Creek and Pacheco Syncline sections, questionable *L. welchi* specimens are found in strata assigned to the Penutian (fig. 4.8). The range of this species is therefore P11 through P15 with questionable occurrences in P9 and P10.

*Lituotuba lituiformis* (Brady) = *Lituotuba* cf. *L. lituiformis* (Brady) - - Mallory (1959), p. 109, pl. 1, fig. 17. - - Mallory (1970), p. 29. - - McDougall (1991), p. 43.

**Range:** *Lituotuba lituiformis* ranges from the Late Cretaceous through at least P8 (Kaminski and others, 1988). Mallory (1959) recognized this species in the late Ynezian, early Penutian, and Ulatisian Stages. Ulatisian and Narizian occurrences are from the Media Agua Creek section in the interval now assigned to the Penutian Stage (zones P7 through early P9 and CP10 through CP12). Other Narizian and Ulatisian occurrences noted by Mallory (1959) are in sections not examined in this study. The cosmopolitan range (Cretaceous to P8) is tentatively accepted pending further study.

*Loxostomoides applinae* (Plummer) - - Berggren and Aubert (1983), pl. 3, fig. 21. - - van Morkhoven and others (1986), p. 327-329, pl. 106, figs. 1-3. = *Loxostomum applinae* (Plummer) - - Mallory (1959), p. 202, pl. 17, fig. 1. - - Mallory (1970), p. 113-114. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 141, 146 (list). = *Bulimina* cf. *B. applini* Plummer - - Mallory and others (1998), p. 257 (list). = *?Loxotomum delicatulum* (Cushman) - - Smith (1957), p. 176, pl. 25, fig. 4. = *Loxotomium plaitum* (Carsey) - - Mallory and others (1998), p. 254.

**Range:** *Loxostomoides applinae* ranges from early Paleocene zone P1 through late early Eocene zone P6b with rare occurrences in early Eocene zones P7 through P9 (van Morkhoven and others, 1986). Mallory (1959) gives the range of this species as Ynezian through Ulatisian, which encompasses almost the same interval. The Ulatisian occurrences noted by Mallory (1959) in Media Agua Creek are in the interval that includes planktic foraminifers assigned to zone P8, calcareous nannoplankton assigned to CP12, and benthic foraminifers now assigned to the Penutian Stage (fig. 4.8).

**Ecology:** *Loxostomoides applinae* is a neritic taxa but may also occur at upper bathyal depths (Ingle, 1980; van Morkhoven and others, 1986).

*Neoeponides hillebrandti* Fisher - - Tjalsma and Lohm-

ann (1983), p. 16, pl. 7, fig. 9a-b.

**Range:** *Neoeponides hillebrandti* ranges throughout most of the Paleocene, zones P1 to P5 (Tjalsma and Lohmann, 1983).

**Ecology:** *Neoeponides hillebrandti* has a wide bathymetric range with most abundant occurrences at abyssal depths during the early Paleocene and bathyal depths during the late Paleocene (Tjalsma and Lohmann, 1983).

*Neoflabellina jarvisi* (Cushman) and *Neoflabellina semireticulata* (Cushman and Jarvis)

**Range:** Species of *Neoflabellina* were not recognized by Mallory (1959) or other early workers in the Tertiary of California. *Flabellina pilulifera* was recognized by Goudkoff (1945) in his zone A (= Cheneyian) and is probably synonymous with one of the three *Neoflabellina* species listed here. Three species—*N. jarvisi* and *N. semireticulata*—are recognized in more recent studies, and their restricted ranges (Cretaceous through P5; Tjalsma and Lohmann, 1983; van Morkhoven and others, 1986; Berggren and Miller, 1989) make them extremely useful for identifying Paleocene strata.

**Ecology:** Wide bathymetric range with most abundant occurrences at abyssal depths during the early Paleocene and bathyal depths during the late Paleocene (Tjalsma and Lohmann, 1983). *Neoflabellina semireticulata* may be the deep water variation of *N. jarvisi* (van Morkhoven and others, 1986).

*Nuttaloides truempyi* (Nuttall) - - Berggren and Aubert (1983), pl. 4, figs. 2,3,4. = *Asterigerina crassaformis* Cushman and Siegfus - - Smith (1957), p. 186-187, pl. 28, figs. 7,10. - - Mallory (1959), p. 242, pl. 37, fig. 13a,b,c. - - Mallory (1970), p. 137. - - Mallory and others (1998), p. 258 (list). = *Asterigerina crassaformis umbilicatula* Mallory (1959), p. 242, pl. 22, fig. 1a,b,c. - - Mallory (1970), p. 137. - - Almgren and others (1988), fig. 5 (list). - - Mallory and others (1998), p. 255, 258 (list). = *Asterigerinoides crassaformis* (Cushman and Siegfus) - - Kleinpell and Mallory (1998), p. 234, 237 (list). = *Asterigerinoides crassaformis umbilicatula* (Mallory) - - Kleinpell and Mallory (1998), p. 234 (list).

**Range:** *Nuttaloides truempyi* ranges from the Late Cretaceous (Campanian) through late Eocene zone P17 (van Morkhoven and others, 1986). Mallory (1959) gives the range of *Asterigerina crassaformis* as Ulatisian through Narizian and *A. crassaformis umbilicatula* as Penutian through Narizian. Because only limited Paleocene strata were examined, no Paleocene occurrences were noted by Mallory (1959). This species is, however, present in the Media Agua Creek (Penutian through Ulatisian),

Arroyo el Bulito (Ynezian through Penutian), Pacheco Syncline (Penutian through Ulatisian), Vaca Valley (Ulatisian) and the Devils Den (Narizian) sections. The range of *Asterigerina crassaformis umbilicatula* given by Almgren and others (1988) is zones C through A-2, which is coeval with zones CP9 through CP14 (zones P7 to P14) and also falls within the broader cosmopolitan range of *Nuttaloides truempyi*. Berggren and Aubert (1983) considered the extinction of *N. truempyi* a useful event for identification of the Eocene/Oligocene boundary in deep-water sediments.

**Ecology:** Along the East Pacific margin, the upper depth limit of *N. truempyi* is in the lower bathyal biofacies (1,500 to 2,000 m) (Ingle, 1980), but *N. truempyi* is most common at abyssal depths (van Morkhoven and others, 1986).

*Nuttallinella florealis* (White) = *Gyroidina florealis*  
White - - Mallory (1959), p. 234, pl. 21, fig. 2. - - van Morkhoven and others (1986), p. 356-358, pl. 115.

**Range:** *Nuttallinella florealis* ranges from the Cretaceous through the late Paleocene P5 zone (van Morkhoven and others, 1986; Berggren and Miller, 1989). Mallory (1959) noted *N. florealis* (*G. florealis*) in the Ynezian through Penutian; Penutian and Ulatisian occurrences were noted by Laiming (1940). The Penutian occurrences in the Devils Den section have not been verified and the species not found in subsequent studies of this area (Berggren and Aubert, 1983). The location of the reported Ulatisian occurrence is unknown. In the sections examined for this study, *N. florealis* is present in the Ynezian through Penutian (CP9 and CP11) of the Arroyo el Bulito section (fig. 4.7). The Penutian specimens in the Arroyo el Bulito section may be *N. truempyi*, a similar species.

*Osangularia mexicana* (Cole) - - Berggren and Aubert (1983), pl. 4, figs. 13,14. - - Tjalsma and Lohmann (1983), p. 35, pl. 20, fig. 6. = *Eponides lodoensis martini* Smith (1957), p. 182 (in part). = *Parrella culter midwayensis* (Cushman) - - Mallory (1959), p. 239, pl. 21, fig. 7. - - Kleinpell and Mallory (1998), p. 236 (list). = *Parrella culter* (Parker and Jones) - - Browning and others (1998), p. 147 (list). = *Osangularia culter* - - Gibson (1976), Table 2 (list). = *Parrella tenuicarinata* - - Mallory (1959), p. 240, pl. 21, fig. 5. - - Kleinpell and Mallory (1998), p. 236 (list).

**Range:** Tjalsma and Lohmann (1983) give the range of *O. mexicana* as early Eocene (P6b) through the Oligocene (P22). Forms identified by Mallory (1959) as *Parrella culter midwayana* and *Parrella tenui-*

*carinata* range from early Ynezian through the early Narizian, and late Bulitian through late Narizian. The early Ynezian occurrence of *P. midwayana* is from the Media Agua Creek section in the interval now assigned to the early Eocene, Penutian Stage (fig. 4.8). The Bulitian occurrence of *P. tenuicarinata* is not identified (Mallory, 1959). The ranges of these synonymous California species are therefore early Eocene to Oligocene as noted by Tjalsma and Lohmann (1983).

**Ecology:** Along the East Pacific margin, *O. mexicana* has an upper depth limit in the upper middle bathyal biofacies (Ingle, 1980).

*Palmula primitiva* Cushman - - Smith (1957), p. 169, pl. 23, fig. 7. - - Mallory (1959), p. 159, pl. 32, fig. 4, pl. 36, fig. 9. - - Mallory and others (1998), p. 257 (list). - - Browning and others (1998), p. 147 (list).

**Range:** *Palmula primitiva* ranges from the Late Cretaceous through Paleocene (P6a?) (Sliter, 1968). Mallory (1959) restricted this species to the Ynezian. Occurrences in the sections examined in this study support a Cretaceous through Paleocene range for this species.

*Plectofrondicularia miocenica* Cushman - - Kleinpell (1938), p. 240, pl. 7, fig. 12. - - Smith (1956), p. 94, pl. 12, fig. 8. = *Parafrondicularia miocenica* (Cushman) - - Finger (1990), p. 188-189, plate-figs. 1-11.

**Range:** Kleinpell (1938) gives the range of *P. miocenica* as Zemorrian through Relizian (late Oligocene through middle Miocene); Finger (1990) gives the range of *P. miocenica* as Oligocene to Pliocene, which is coeval with P18 through N21. This species is noted in the Devils Den section in association with latest Refugian faunas and in strata assigned to chron C15r, which is latest Eocene (Prothero, 2001b). A range of P18 through N21 with a questionable occurrence in P17 is therefore proposed for this species.

**Ecology:** The upper depth limit of *P. miocenica* is in the lower middle bathyal biofacies (Ingle in Finger, 1990). Ingle (1980) lists *P. miocenica laimengi* as having an upper depth limit in the lower bathyal biofacies ( $\geq 2,000$  m). This variety has a broad flat periphery instead of the acute keeled periphery of *P. miocenica*, and thus, probably has a shallower upper depth limit.

*Plectofrondicularia packardi* Cushman and Schenck - - McDougall (1980), p. 37. - - Kleinpell and Mallory (1998), p. 239 (list). = *Plectofrondicularia packardi packardi* Cushman and Schenck - - Smith (1956), p. 94, pl. 12, figs. 1,7. - - Tipton (1980), p. 265 (list),

275. = *Plectofrondicularia packardi multilineata* Cushman and Simonson - - Smith (1956), p. 94, pl. 12, fig. 6. - - Tipton (1980), p. 265 (list), 275. = *Plectofrondicularia packardi robusta* Kleinpell and Weaver - - Tipton (1980), p. 265 (list), 275.

**Range:** This species includes a number of variants that probably represent ecological variations within the range of *P. packardi*. *Plectofrondicularia packardi* ranges from the late Narizian into the Oligocene (Mallory, 1959; McDougall, 1980; Tipton, 1980). This species has, however, been found throughout the Narizian as well as the Oligocene so the range is tentatively given as P15 through P22 with questionable or rare occurrences in P13 and P14. *Plectofrondicularia packardi* is present in the Devils Den, Arroyo el Bulito and Seaboard Welch Well #1 sections.

*Plectofrondiularia paucicostata* Cushman and Jarvis - - van Morkhoven and others (1986), p. 273, pl. 91, figs. 1-2. = *Plectofrondicularia kerni* Cook - - Mallory (1959), p. 212, pl. 18, fig. 2; pl. 33, fig. 10a,b. - - Mallory (1970), p. 99-100. - - Berggren and Aubert (1983), pl. 2, fig. 8.

**Range:** *Plectofrondicularia paucicostata* ranges from the middle Eocene (P12) through early Oligocene (P20) with questionable or rare occurrence from early Eocene P8 through middle Eocene P11 (van Morkhoven and others, 1986). Mallory (1959) gives the range of *P. kerni* as early Penutian through early Narizian. In the sections studied here *P. paucicostata* ranges from the Penutian through Narizian (P7 to P11), which represents only the questionable or rare part of the cosmopolitan range of *P. paucicostata*.

**Ecology:** *Plectofrondicularia paucicostata* is a middle bathyal to abyssal species (van Morkhoven and others, 1986).

*Pullenia eocenica* Cushman and Siegfus - - Mallory (1959), p. 246, pl. 30, fig. 4a,b. - - Mallory (1970), p. 142, pl. 12, fig. 4. - - Tjalsma and Lohmann (1983), p. 36, pl. 16, fig. 2. - - Boyd (1998), p. 125 (list) - - Browning and others (1998), p. 147 (list). - - Kleinpell and Mallory (1998), p. 236, 240 (list). - - Mallory and others (1998), p. 257 (list).

**Range:** *Pullenia eocenica* is common from early Eocene zone P9 through late Eocene P17 with rare occurrences as old as P6a (late Paleocene) (Tjalsma and Lohmann, 1983). According to Mallory (1959), *P. eocenica* ranges from late Bulitian through late Narizian, however the older occurrences in Media Agua Creek section are now assigned to the Penutian. In the Arroyo el Bulito section *P. eocenica* ranges from the Cheneyian (P1/P3) through Bulitian

(?) (CP11) portion of the section. *Pullenia eocenica* is also recognized in the Ynezian of the Simi Valley section coeval with zone P4. The Eocene range of *P. eocenica* is accepted and the Paleocene occurrences in the sections examined here are assumed to be misidentified.

**Ecology:** Along the East Pacific margin, *P. eocenica* has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980).

*Silicosigmoilina californica* Cushman and Church - - Smith (1957), p. 155, pl. 19, figs. 8 and 12. - - Mallory (1959), p. 129. - - Mallory (1970), p. 50. - - Gibson (1976), Table 2 (list). - - Heitman (1983), fig. 4 (list). - - Almgren and others (1988), fig. 5 (list). - - Berggren and Aubert (1983), pl. 1, fig. 19. - - Browning and others (1998), p. 142, 148, 152 (list). - - Kleinpell and Mallory (1998), p. 236 (list). - - Mallory and others (1998), p. 257 (list).

**Range:** *Silicosigmoilina californica* is probably a junior synonym of *Rzehakina epigona* (Rzehak). The range of *R. epigona* is Late Cretaceous (Campanian through early Eocene (P9) with doubtful occurrences in middle Eocene zones P10 through P13 (van Morkhoven and others, 1986). Mallory (1959) records *S. californica* as present in the Paleocene and Eocene in California. Almgren and others (1988) indicate this species ranges from zone D through A-2, which is equivalent to nannofossil zone CP4 through CP14 (planktic foraminiferal zones P4 through P14). Only rare or questionable occurrences of *S. californica* are noted in zone A-2 (P10 to P14) (Almgren and others, 1988). In the sections examined for this study *S. californica* is common in the Paleocene through middle Eocene coeval with zones P1 through P13, although the middle Eocene occurrences are not as common. Therefore the range suggested by van Morkhoven and others (1986) is accepted.

**Ecology:** *Rzehakina epigona* is common in bathyal and abyssal environments (van Morkhoven and others, 1986).

*Spiroplectammina directa* (Cushman and Siegfus) - - Mallory (1959), p. 116, pl. 3, fig. 5a,b. - - Mallory (1970), p. 37. - - Gibson (1976), Table 2 (list). - - Berggren and Aubert (1983), pl. 1, fig. 8, 9. - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 142, 148 (list). - - Kleinpell and Mallory (1998), p. 236, 240 (list).

**Range:** *Spiroplectammina directa* is probably a junior synonym of *S. specialis* that ranges from the Cretaceous to late middle Eocene planktic foraminiferal zone P14 (approximately 40 Ma, Gradstein and others, 1988). *Spiroplectammina directa* was

thought to be restricted to the Ulatisian and Narizian Stages (Mallory, 1959). This species has, however, been found in Paleocene and early Eocene assemblages in association with calcareous nannofossil assemblages (CP6 through CP11 as well as in the middle Eocene). The cosmopolitan range given by Gradstein and others (1988) of *S. directa* (Cretaceous to P14) is used.

*Spiroplectammina richardi* Martin - - Mallory (1959), p. 118, pl. 3, fig. 9; pl. 27, fig. 5. - - Mallory (1970), p. 38. - - Berggren and Aubert (1983), pl. 1, fig. 7. - - Kleinpell and Mallory (1998), p. 236 (list). = *Spiroplectammina?* cf. *S. richardi* Martin - - Mallory (1959), p. 118, pl. 3, fig. 10. - - Mallory (1970), p. 39. = *Spiroplectammina adamsi* Lalicker - - Smith (1957), p. 150-151, pl. 18, figs. 4a-b. - - Mallory (1970), p. 37. - - Browning and others (1998), p. 148 (list). = *Spiroplectammina adamsi* Lalicker - - Smith (1957), p. 150-151, pl. 18, fig. 4. = *Spiroplectammina* cf. *S. adamsi* Lalicker - - Mallory (1970), p. 37. = *Spiroplectammina gryzbowski* Frizzell - - Gibson (1976), Table 2 (list). - - Almgren and others (1988), fig. 5 (list). - - Heitman (1983), fig. 4 (list). - - Browning and others (1998), p. 142, 148 (list). - - Mallory and others (1998), p. 257 (list). = *Spiroplectammina gryzbowski* Frizzell - - Browning and others (1998), p. 148 (list). = *Spiroplectammina mississippiensis* Cushman - - Mallory (1970), p. 38. - - Vaughan (1976), p. 80. - - Boyd (1998), p. 123 (list). = *Textularia mississippiensis* (Cushman) - - Smith (1957), p. 151-152, pl. 18, figs. 1-3. = *Spiroplectammina perplexa* Israelsky - - Mallory (1970), p. 38.

**Comments:** *Spiroplectoides clotho* (Gryzbowski) of Goudkoff (1945, Table II) may also be a synonym of *S. richardi*.

**Range:** *Spiroplectammina richardi* has been identified under a variety of names in California strata. The range given by Mallory (1959) is early Bulitian through early Narizian. *Spiroplectammina richardi* (*S. gryzbowski*) occurs in zones E through A-2 of Almgren and others (1988), which are coeval with planktic zones P4 through P15. In the sections examined for this study, *S. richardi* is common in the Ynezian through early Narizian coeval with zones P4 through P10. Because younger occurrences were noted by Almgren and others (1988), the younger range of this species in zones P11 through P15 is tentatively accepted but questioned. If *S. clotho* is synonymous with this species, the range of *S. richardi* would be extended into the early Paleocene, zone P1.

**Ecology:** Along the East Pacific margin, *S. richardi* has an upper depth limit in the outer shelf biofacies (50 to 150 m) (Ingle, 1980).

*Stensioina beccariiformis* (White) - - van Morkhoven and others (1986), p. 346-353, pls. 113A, B, C, and D. = *Gavelinella beccariiformis* White - - Almgren and others (1988), fig. 5 (list) = *Pseudovalvulineria beccariiformis* - - Gibson (1976), Table 2 (list).

**Range:** *Stensioina beccariiformis* was not recognized by earlier workers in California micropaleontology. It has been recognized as a cosmopolitan species that ranges from the Late Cretaceous (Santonian) through late Paleocene (P5) (van Morkhoven and others, 1986). Almgren and others (1988) considered this species diagnostic of their upper E zone, which is coeval with planktic foraminiferal zones P4 and P5.

*Tappanina selmensis* (Cushman) - - van Morkhoven and others (1986), p. 332-334, pl. 108, figs. 1-3.

**Range:** Although *T. selmensis* was not recognized by previous workers in California, it has now been found in the Paleocene of Lodo Gulch and Smith Grade (Locatelli Formation; Berggren and Aubert, 1983). The range of *T. selmensis* is Maastrichtian through early Eocene (P6b) (van Morkhoven and others, 1986).

**Ecology:** *Tappanina selmensis* is an outer neritic species but is also found in bathyal facies (van Morkhoven and others, 1986).

*Trifarina wilcoxensis* (Cushman and Ponton) = *Angulogerina wilcoxensis* (Cushman and Ponton) - - Smith (1957), p. 179, pl. 25, fig. 9. - - Mallory (1959), p. 211, pl. 37, fig. 6. - - Mallory (1970), p. 117, pl. 8, fig. 5. - - Heitman (1983), fig. 4 (list). - - Brownning and others (1998), p. 142, 149 (list). = *Angulogerina* cf. *A. wilcoxensis* (Cushman and Ponton) - - Vaughan (1976), p. 67. - - Berggren and Aubert (1983), pl. 3, fig. 14.

**Range:** *Trifarina wilcoxensis* ranges from late Bulitian through early Penutian with a questionable occurrence in the late Ulatisian (Mallory, 1959). Almgren and others (1988) give the range as zones C through B-4, coeval with planktic zones P6b through late P8. In this study *T. wilcoxensis* was found in the Paleocene of the Simi Valley section (fig. 4.13) but this occurrence is suspect due to taxonomic problems encountered in this section. Other occurrences of *T. wilcoxensis* suggest this species ranges from the Penutian through Ulatisian (P7 to P10).

**Ecology:** Along the East Pacific margin, *T. wilcoxensis* has an upper depth limit on the outer shelf biofacies and is transitional to upper bathyal biofacies (Ingle, 1980).

*Uvigerina atwilli* Cushman and Simonson - - Smith (1956), p. 96, pl. 12, fig. 10. - - Tipton (1980), p. 265 (list), 275. = *Uvigerina* cf. *U. atwilli* Cushman

and Simonson - - Kleinpell and Mallory (1998), p. 240 (list).

**Range:** *Uvigerina atwilli* is restricted to the Refugian Stage coeval with zones P16 and P17 (McDougall, 1980; Tipton, 1980).

**Ecology:** *Uvigerina glabrans* is common at upper bathyal depths in carbonate rich foraminiferal sands. Along the Pacific margin, *U. atwilli* occurs most frequently in association with outer shelf and upper bathyal assemblages (McDougall, 1980).

*Uvigerina alabamensis* - - Mallory (1959), p. 206, pl. 29, fig. 5a,b,c. - - Berggren and Aubert (1983), p. 11.

**Range:** The range of *U. alabamensis* is given as Penutian through Ulatisian by Mallory (1959). It has been recognized in the Penutian of the Lodo Gulch section (Berggren and Aubert, 1983) and the Ulatisian of the Vaca Valley section (Mallory, 1959). This species is probably unrecognized in most studies because of its small size. Until more data on the occurrence of this species is available, a broad range of zones P6b through P12 will be used.

*Uvigerina churchi* Cushman and Siegfus - - Mallory (1959), p. 206, pl. 17, fig. 6. - - Mallory (1970), p. 115, pl. 8, fig. 2. - - Kleinpell and Mallory (1998), p. 237 (list). = *Uvigerina churchi demicostata* Mallory (1959), p. 207, pl. 17, fig. 10. - - Mallory (1970), pl. 8, fig. 1. - - Vaughan (1976), p. 80. - - Kleinpell and Mallory (1998), p. 237 (list).

**Range:** Mallory (1959) gives the range of *Uvigerina churchi* as Narizian, however, in sections examined for this study, *U. churchi* occurs in the Ulatisian and Narizian of the Media Agua Creek, Vaca Valley and Devils Den sections. It is not present in the Refugian. The range of *U. churchi* is tentatively given as zones P10 through P15.

*Uvigerina cocoaensis* Cushman - - Smith (1956), p. 96, pl. 12, fig. 11. - - Tipton (1980), p. 265 (list), 275. - - McDougall (1980), p. 38, pl. 16, figs. 4-13; pl. 17, figs. 1-10. - - Kleinpell and Mallory (1998), p. 240 (list).

**Range:** Although Tipton (1980) restricts this species to the middle and late Refugian Stage, McDougall (1980) considers its first appearance datum to be in the early Refugian, coeval with P15. The species does not appear in the Zemorrian. The range of *U. cocoaensis* is therefore given as P16 through P17.

*Uvigerina elongata* Cole - - Smith (1957), p. 177, pl. 26, fig. 11. - - Mallory (1959), p. 207, pl. 29, fig. 4. - - Mallory (1970), p. 115, pl. 8, fig. 3. - - Vaughan

(1976), p. 80. -- Berggren and Aubert (1983), pl. 3, fig. 16, 17.

**Range:** Mallory (1959) gives the range of *U. elongata* as late Bulitian through early Narizian. The Bulitian occurrence is in Media Agua Creek section and is now assigned to the Penutian (zone P7); the remaining occurrences are Ulatisian coeval with zone P9 through P11. The cosmopolitan range of *U. elongata* is middle Eocene (zone P9) through Oligocene (zone P20) (Boersma, 1984), which is accepted here despite the rare Penutian occurrence in the Media Agua Creek section.

**Ecology:** Boersma (1984) finds *U. elongata* in shallow shelf sediments, frequently in warmer regions and associated with glauconite.

*Uvigerina gallowayi* Cushman -- Tipton (1980), p. 275.

**Range:** The range of *U. gallowayi* is given as early through late Miocene, coeval with zones N4 to N15 and possibly N16 (Boersma, 1984). Kleinpell (1938) noted the presence of this species in the early Zemorrian, early Oligocene. This species is also present in the late Refugian in California (Tipton, 1980). The range of *U. gallowayi* is therefore P16 through N15 and possibly N16.

**Ecology:** *Uvigerina gallowayi* has an upper depth limit in the upper middle bathyal biofacies (500 to 1,500 m) (Ingle, 1980).

*Uvigerina garzaensis* Cushman and Siegfus -- Smith (1956), p. 97, pl. 13, fig. 2. -- Smith (1957), p. 177, pl. 26, fig. 9. -- Mallory (1959), p. 208, pl. 37, fig. 2a,b. -- Mallory (1970), p. 115-116. -- Tipton (1980), p. 265 (list), 269, 271. -- Kleinpell and Mallory (1998), p. 237, 240 (list). = *Uvigerina garzaensis nudorobustata* Mallory (1959), p. 208, pl. 17, figs. 11,13. -- Mallory (1970), p. 116. -- Vaughan (1976), p. 81. -- Tipton (1980), p. 275. -- Kleinpell and Mallory (1998), p. 240 (list).

**Range:** Although the range of this hispid uvigerinid and its ecologic variants is given as early Narizian through Refugian (Mallory, 1959; Tipton, 1980), it probably has a more extensive range, particularly in deeper water. In the sections examined for this study, *U. garzaensis* ranges from Ulatisian through Refugian and probably extends into the Zemorrian. A range from the Ulatisian through Refugian, coeval with zones P10 through at least P17, is tentatively accepted for this species.

**Ecology:** Along the East Pacific margin, *U. garzaensis* has an upper depth limit in the lower bathyal biofacies (Ingle, 1980).

*Uvigerina laimingi* Smith (1957), p. 177-178, pl. 26, fig. 4a-c, 8a-c. -- Mallory (1959), p. 208-209. = *Pseudouvigerina sp. C* -- Laiming (1940), p. 553.

-- Almgren and others (1988), fig. 5 (list).

**Range:** *Uvigerina laimingi* was found only in the Ynezian of Pacheco Syncline by Mallory (1959). The range of this species is therefore Paleocene and restricted to the Ynezian Stage, coeval with zone P4.

*Uvigerina lodoensis miriamae* Mallory (1959), p. 209, pl. 17, figs. 8-9; **not** pl. 40, fig. 9. -- Mallory (1970), p. 116. -- Berggren and Aubert (1983), pl. 3, figs. 18, 19, 20. -- Browning and others (1998), p. 152 (list). = *Uvigerina cf. U. lodoensis* Martin -- Smith (1957), p. 178, pl. 25, fig. 7. = *Uvigerina* spp., Smith (1957), p. 179, pl. 25, fig. 10, **not** pl. 26, fig. 3. = *Pseudouvigerina vacavillensis* Boyd (1949), p. 48, pl. II, fig. 35. -- Vaughan (1976), p. 79.

**Range:** Mallory (1959) gives the range of *U. lodoensis miriamae* as Penutian through Ulatisian. Specimens occur in the Penutian of the Media Agua Creek and Pacheco Syncline sections, coeval with zones late P7 to P9. The range of *U. lodoensis miriamae* in California appears to continue into younger strata as it has been observed in the Poppin shale of Classen and Hornaday (1998; informal term for a shale member of the Anita Formation), which is early Ulatisian (CP12a, Bukry, unpublished paleontologic report, 1989; planktic foraminiferal zone P10). Other Ulatisian occurrences given by Mallory (1959) have not been confirmed. This species is probably a synonym of *Uvigerinella abbreviata*, which King (1989) has found in the North Sea. *Uvigerinella abbreviata* ranges from NSB3a to 3b (equivalent to late P6b to early P9) in the North Sea and to the middle Eocene in the onshore sequences (King, 1989). The range of *U. lodoensis miriamae* is therefore given as P6b through P9 and questionably as young as P10.

*Vaginulinopsis asperuliformis* (Nuttall) -- Mallory (1959), p. 155, pl. 27, fig. 20a,b. -- Mallory (1970), p. 73. -- Vaughan (1976), p. 81. -- Almgren and others (1988), fig. 5 (list). -- Berggren and Aubert (1983), pl. 2, figs. 4, 5. -- Kleinpell and Mallory (1998), p. 237 (list). -- Mallory and others (1998), p. 259 (list). -- Browning and others (1998), p. 149 (list). = *Vaginulinopsis cf. V. asperuliformis* (Nuttall) -- Mallory (1970), p. 72, pl. 4, fig. 11. -- Browning and others (1998), p. 152 (list).

**Range:** Mallory (1959) gives the range as late Bulitian through early Narizian; Almgren and others (1988) give the range as zone C through A-2 (rare), which corresponds to nannofossil zones CP9 through CP14 (planktic foraminiferal zones P6b to P14). In the sections examined for this study *V. asperuliformis* ranges from early Eocene Penutian through early Narizian, coeval with P6b through P14.

**Ecology:** Along the East Pacific margin, *V. asperuliformis* has an upper depth limit in the outer shelf biofacies (50 to 150 m) (Ingle, 1980).

*Vaginulinopsis nudicostata* (Cushman and Hanna) = *Vaginulinopsis mexicana nudicostata* (Cushman and Hanna) - - Smith (1957), p. 162, pl. 22, fig. 3. - - Mallory (1959), p. 157, pl. 28, fig. 1; pl. 40, figs. 2-3. - - Mallory (1970), p. 74, pl. 4, fig. 13. - - Vaughan (1976), p. 81. - - Berggren and Aubert (1983), pl. 2, fig. 6. - - Boyd (1998), p. 122, 123 (list). - - Browning and others (1998), p. 152 (list). = *Vaginulinopsis mexicana* var *B* - - Almgren and others (1988), fig. 5.

**Range:** Mallory (1959) gives the range as lower Bulitian through upper Ulatisian, but the Paleocene occurrences were in the Media Agua Creek section and have now been assigned to the Penutian (fig. 4.8). Almgren and others (1988) give the range as zones B-4 through B-1, which are equivalent to late P8 through early P10. This range is consistent with the observed occurrences in the studied sections.

*Vaginulinopsis saundersi* (Hanna and Hanna) - - Smith (1957), p. 162, pl. 22, figs. 1-2. - - Mallory (1959), p. 157, pl. 11, fig. 10. - - Mallory (1970), p. 75. - - Tipton (1980), p. 265 (list), 267, 275. - - Heitman (1983), fig. 4 (list). = *Vaginulinopsis* (?) aff. *V. saundersi* (Hanna and Hanna) - - Smith (1957), p. 163, pl. 22, fig. 4. = *Marginulina mexicana* var *C* - - Almgren and others (1988), fig. 5 (list). = *Vaginulinopsis mexicana* var *C* (Laiming, 1940) - - Boyd (1998), p. 123.

**Range:** The range according to Mallory (1959) is Bulitian through Ulatisian; Almgren and others (1988) give the range as zones B-4 through B-2, which are equivalent to nannofossil zones CP10 through CP11 (planktic foraminiferal zones late P7 to P9). Mallory's (1959) Bulitian occurrence in the Media Agua Creek section is now assigned to the Penutian and coeval with zone P7 (fig. 4.8). In the sections examined for this study, *Vaginulinopsis saundersi* occurs in the late Paleocene or early Eocene of the Media Agua Creek, Simi Valley, Pacheco Syncline, and Vaca Valley sections. Excluding the Paleocene occurrences in the Simi Valley and Pacheco Syncline sections (probably misidentified), this species appears to range from the Penutian through the early Ulatisian coeval with zones P7 through P9. Tipton (1980) also reports this species from the middle Refugian Stage in the Gaviota section. Until the Paleocene and late Eocene occurrences are resolved, the range of *V. saundersi* is P7 through P9 with questionable occurrences in P4 through P6 and P10 through P16.

*Vaginulinopsis vacavillensis* (Hanna) - - Smith (1957), p. 163, pl. 22, figs. 6,7,8. - - Vaughan (1976), p. 81. - - Boyd (1998), p. 122, 123 (list). = *Vaginulinopsis mexicana vacavillensis* (Hanna) - - Mallory (1959), p. 157, pl. 11, fig. 8, pl. 40, figs. 1,7. = *Vaginulinopsis mexicana* var *A* - - Almgren and others (1988), fig. 5 (list).

**Range:** Mallory (1959) gives the range of *V. vacavillensis* as late Ynezian through late Ulatisian, however he does not provide references to the Ynezian or Bulitian occurrences, citing only Penutian and Ulatisian occurrences. Almgren and others (1988) give the range as zones B-3/B-2 through B-1, which are coeval with CP11 through CP12 (or planktic zones P8 to P10). This range is consistent with the occurrences noted in the sections examined for this study. *V. vacavillensis* is noted in the Pacheco Syncline area, where it occurs in Ulatisian strata assigned to calcareous nannoplankton zone CP12 and in the Ulatisian of the Vaca Valley section coeval with CP11 and CP12 (P9 to P10).

*Vaginulinopsis verruculosa* Martin (1943), p. 16, pl. 5, fig. 6 - - Smith (1957), p. 164, pl. 21, fig. 19. - - Mallory (1959), p. 158, pl. 36, fig. 8. - - Mallory (1970), p. 75-76, pl. 5, fig. 2. = *Marginulina mexicana* var *D* Laiming (1940), p. 198, pl. 83, fig. 7. = *Vaginulinopsis mexicana* var *D* (Laiming) - - Almgren and others (1988), fig. 5 (list).

**Range:** Mallory (1959) gives the range of *V. verruculosa* as late Bulitian through late Ulatisian. Almgren and others (1988) indicate that this species ranges from their B-4 and B-3/B-2, and Pseudo-C zones but is missing in the B-1 zone, which gives a range coeval with calcareous nannoplankton zones CP10 and CP11 (or planktic zones P7 to early P9). Mallory's (1959) Bulitian occurrence is in the Media Agua Creek section, which is now assigned to the Penutian (fig. 4.8). A Penutian range coeval with zones P7 through P9 is compatible with the observed occurrences in the sections examined for this study.

*Valvulineria jacksonensis welcomensis* Mallory (1959), p. 231, pl. 20, figs. 3a,b,c; 5a,b,c. - - Mallory (1970), p. 129, pl. 10, fig. 6. - - Tipton (1980), p. 265 (list). - - Kleinpell and Mallory (1998), p. 237, 240 (list). = *Valvulineria* cf. *V. jacksonensis welcomensis* Mallory - - Vaughan (1976), p. 81. = *Valvulineria martinezensis* Smith (1957), p. 180, pl. 27, figs. 1, 4.

**Range:** Mallory (1959) gives the range of *V. jacksonensis welcomensis* as Narizian through Refugian. In the sections examined for this study *V. jacksonensis welcomensis* occurs in the Vaca Valley, Devils Den, Arroyo el Bulito, and Seaboard Welch Well #1 sec-

tions. The Vaca Valley occurrence is in the Ulatian Stage and coeval with zones P10/11 through P12. The occurrence in zones P10/11 is questioned. The Narizian and Refugian occurrences are coeval with Chrons C20n or C21n through C19n or C20n (Devils Den, fig. 4.10), and zone P15 (Arroyo el Bulito, fig. 4.11). A range of Ulatian through Refugian, coeval with zones P12 through P16, is tentatively suggested for this species.

*Valvulineria tumeyensis* Cushman and Simonson - - Mallory (1959), p. 232. - - Tipton (1980), p. 265 (list), 275. - - Kleinpell and Mallory (1998), p. 240 (list). = *Valvulineria chirana* Cushman and Stone - - Smith (1957), p. 180, pl. 27, fig. 2.

**Range:** *Valvulineria tumeyensis* ranges from the early Narizian through the Refugian (Mallory, 1959;

McDougall, 1980; Tipton, 1980), coeval with zones P13 through P16.

*Zeauvigerina lodoensis* Martin - - Mallory (1959), p. 211. - - Mallory (1970), p. 101

**Range:** Mallory (1959) cites a rare occurrence of *Zeauvigerina lodoensis* in the Ynezian of the Media Agua Creek section, the early Penutian in Lodo Gulch (Martin, 1943), and the early Ulatian of the Devils Den section. The Media Agua Creek occurrence is now assigned to the Penutian Stage and coeval with planktic foraminiferal zone P6b, as is the Lodo Gulch occurrence. The Devils Den occurrence cannot be located so the Ulatian portion of the range is unsupported. The range of *Z. lodoensis* is Penutian, coeval with zones P6b through P8.