This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.
ABSTRACT

Planktic transoceanic coccolith zones that have been identified and published for California Cenozoic geologic formations are summarized for reference in correlation work. The summary includes literature reports of 62 formational units that range from upper Paleocene (Zone CP4) to upper Pliocene (Zone CN12).

INTRODUCTION

Coccolith biostratigraphy was first applied to California marine geologic formations by Bramlette and Riedel (1954). For example, the guide fossil *Discoaster lodoensis* Bramlette and Riedel was reported from the lower Eocene Capay Shale of California and was correlated to Haiti, Trinidad, and France. Also, *Discoaster barbadiensis* Tan was shown to be limited to the Eocene, but to occur in almost every Eocene coccolith assemblage from widely scattered regions in California, France, New Zealand, and Tunisia. The major pioneering work on California assemblages appeared in Bramlette and Sullivan (1961) and Sullivan (1964, 1965). These studies featured detailed species lists of old and newly described taxa, from Paleocene and Eocene formations in California, and were used to identify new biostratigraphic zones that could be recognized in California and in transoceanic localities. Later detailed studies (Gibson, 1976; Warren and Newell, 1980; Poore and others, 1981; and Almgren and others, 1988) examined correlations of many formations and benthic foraminiferal provincial stages using coccolith zonations which had been gradually proven, through
application during the Deep Sea Drilling Project, to be useful for worldwide correlation (Bukry, 1978, 1981a). Unlike the global correlation emphasized by Bramlette and co-authors, many California studies used coccoliths to help explain local or regional formation relationships, such as Almgren and McDougall (1975), Kheradyar (1988), and Kies and Abbott (1982).

This report presents a summary list of specific geologic formations in California from the main publications from 1954 to 1991 that provide coccolith zonal biostratigraphy. Because this is an initial compilation, it is expected that subsequent appendices can add new or missing references on a periodic basis as coccolith work continues at government, industry and university laboratories.

**ZONATION HISTORY**

There has been considerable continuity in the application of coccolith biostratigraphy in California. This occurred because the pioneering development phase (1954-1967) of M. N. Bramlette and F. R. Sullivan overlapped the transition phase to deep-sea studies in works such as Martini and Bramlette (1963) and Bramlette and Wilcoxon (1967) which related early JOIDES offshore biostratigraphy to the onshore framework. The period of regular Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) coring (1968-1991) provided a central focus for applying new biostratigraphic and eco-stratigraphic relations to California formations (Bukry, in press). Cooperation between M. N. Bramlette at Scripps Institution of Oceanography and other La Jolla area nannopaleontologists (D. Bukry, E. D. Milow, P. H. Roth, A. D. Warren, and J. A. Wilcoxon)
in the late 1960's and early 1970's provided a fairly consistent approach to California coccolith zonation. Consistency in coccolith taxonomy was supported by H. Tappan (UCLA) with A. R. Loeblich, Jr., at Chevron's La Habra Research Laboratory, through publication of a series of annotated indexes (for example, see Loeblich and Tappan, 1966, 1971).

Most coccolith biostratigraphy in the 1970's and 1980's for California applied the DSDP zonation (Bukry, 1971, 1973, 1975) which was codified by Okada and Bukry (1980). Because the most published California coccolith biostratigraphers, such as M. V. Filewicz, P. L. Miller, R. Z. Poore, and A. D. Warren, have used a common zonation, there is little conversion problem when correlating results throughout California. Use of the same zonation can also help to corroborate determinations, as for the Goler Formation where independent studies by M. V. Filewicz and D. Bukry produced the same late Paleocene (Zone CP8) correlation (Squires and others, 1988). The Okada and Bukry (1980) zonation with boundary ages from Haq (1983a) is shown (Figures 1a and 1b) as a reference for formation age estimates. The Haq reference was used because it completely dates the CN-, and CP-subzonal system used here. Other more updated time scales that may be referred to include Barron and others (1985), Berggren and others (1985), and Haq and others (1987), especially for the middle to late Miocene CN5 to CN9 (J. A. Barron, verbal communication, 1991).

Planktic coccolith biostratigraphy is a convenient method for correlating to a global standard and type sections (Bramlette and
<table>
<thead>
<tr>
<th>Epoch/Subepoch</th>
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<th>Unit Name</th>
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Figure 1a. Neogene coccolith biostratigraphic units (Okada and Bukry, 1980, Bukry, 1981b, 1985) with age estimates (Haq, 1983a).
<table>
<thead>
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<th>Unit Name</th>
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<td>CP16 c, b, a</td>
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</table>

Figure 1b. Paleogene coccolith biostratigraphic units (Okada and Bukry, 1980) with age estimates (Haq, 1983a).
Sullivan, 1961; Bramlette and Wilcoxon, 1967; Hay and others, 1967). Also, combining this long-range capability with the short duration of many distinctive coccolith species allows more reproducible age resolution than localized benthic faunal changes, such as those of benthic foraminifers and mollusks, over the varied Cenozoic marine depositional conditions in the California area.
PUBLISHED FORMATION NAMES WITH IDENTIFIED COCCOLITH ZONATION AND COUNTY LOCATION

The formation names listed below are reproduced directly as shown in the published text references which are cited under the names. Quotation marks are in the source reference (for example, Gibson, 1976, p. 87; and Sullivan, 1965, p. 1). This list simply reports names from cited references. But the zone codes shown are either a direct reference or an interpretation of a zone name or a species list in the references cited. Formation names and references are listed in alphabetic order.

ALHAMBRA FM.

Zone: CP13.
Location: Contra Costa Co.

ANITA FM.

Zone: CP6, 7, 8, 9a?, 9b, 10, 11, 12a, 12b, and 14.
Location: Santa Barbara Co.

ARDATH SHALE

Zone: CP12b.
Location: San Diego Co.
"BOLADO PARK FM."

Zone: CP6, 8, 9/10, and 11.
Location: San Benito Co.

BUTANO SANDSTONE

Zone: CP10/11, 11, 12, 12b/15, 13, 14, and 14a.
Location: Santa Clara Co., Santa Cruz Co., and San Mateo Co.

CAÑADA FM.

Zone: C9, 10, 11, and 12b.
Location: Santa Barbara Co. (Santa Cruz Island).

CANOAS MEMBER (OF KREYENHAGEN FM.)

Zone: CP12b, 13a, and 13b.
Location: Fresno Co.

CAPAY SHALE

Zone: CP9, 10, and 11.
Location: Contra Costa Co. and Solano Co.
Reference: Almgren and Filewicz, 1984; and Almgren, Filewicz,
CERROS SHALE (MEMBER OF LODO FM.)

Zone: CP10 and CP10/11.

Location: Fresno Co.


CHURCH CREEK FM.

Zone: CP15.

Location: Monterey Co.


COZY DELL FM.

Zone: CP12/13, 13, 13b, and 14a.

Location: Santa Barbara Co.


DOMENINE SANDSTONE

Zone: CP11 and CP12a.

Location: Contra Costa Co., Fresno Co., and Kern Co.

GALLAWAY FM.
Zone: CN3
Location: Mendocino Co.
Reference: Miller, 1981.

GAVIOTA FM.
Zone: CP15b.
Location: Santa Barbara Co.

"GERMAN RANCHO FM."
Zone: CP12b and 14.
Location: Mendocino Co.
Reference: Miller, 1981.

GOLER FM.
Zone: CP8.
Location: Kern Co.

HAMILTON SAND
Zone: CP9.
Location: Contra Costa Co.
IMPERIAL FM.

Zone: CN9/11.
Location: Riverside Co.
Reference: Bukry, unpublished data, 1979, for R. Z. Poore samples RS-7 and -8 from type locality.

IVERSEN BASALT

Zone: CP18/19?
Location: Mendocino Co.
Reference: Miller, 1981.

JOLLA VIEJA FM.

Zone: CP12b and 14a.
Location: Santa Barbara Co. (Santa Cruz Island).

JUNCAL FM.

Zone: CP11, 12, 12a, 12b, and 13/14a.
Location: Santa Barbara Co.

KELLOGG SHALE

Zone: CP13, CP13c and CP14a.
Location: Contra Costa Co.
KREYENHAGEN FM.

Zone: CP11, 12a, 12b, 13a, 13b, 13, 14a, and 14b.
Location: Kern Co.

LAS JUNTAS SHALE

Zone: CP10 and 14.
Location: Contra Costa Co.

LOCATELLI FM.

Zone: CP4.
Location: Santa Cruz Co.

LODO FM.

Zone: CP6, 7, 8, 9, 9b, 10, 11, and 12a.
Location: Fresno Co., Kern Co., San Benito Co.

LOS MUERTOS CREEK FM.

Zone: CP11 and 13.
Location: San Benito Co.

**LUCIA MUDSTONE (MEMBER OF RELIZ CANYON FM.)**

Zone: CP10 and 11.
Location: Monterey Co. and San Benito Co.

**MANIOBRA FM.**

Zone: CP9, 10, and 11.
Location: Riverside Co.

**MARKLEY FM. (UPPER, WHITE SANDS)**

Zone: CP14b.
Location: --

**MARKLEY FM. (UPPER, SIDNEY FLAT SHALE MEMBER)**

Zone: CP13 and 14a.
Location: Contra Costa Co.

"MARKLEY CANYON FILL"

Zone: CP16a and CP16b-c.
Location: Solano Co.

**MARTINEZ FM.**
Zone: CP4, 5, 6, 7, and 8.
Location: Contra Costa Co.

**"MARTINEZ" FM.**
Zone: CP5.
Location: Ventura, Co.

**MATILIJA FM.**
Zone: CP12 and CP13.
Location: Santa Barbara Co.

**"MATILIJA" FM.**
Zone: CP9b.
Location: Santa Barbara Co.

**MEGANOS SHALE**
Zone: CP9.
Location: Contra Costa Co.

MISSION VALLEY FM.

Zone: CP13 and CP14 or higher.
Location: San Diego Co.

MONTEREY FM.

Zone: CN2, 3, 4, 5, 5/8, and 9?.
Location: Orange Co., San Luis Obispo., Santa Barbara Co., Santa Cruz Co., and Ventura Co.

MUIR FM.

Zone: CP14.
Location: Contra Costa Co.

NORTONVILLE FM.

Zone: CP13.
Location: Contra Costa Co.
POINTER ARENA FM.

Zone: CN3, 4, and 5a.
Location: Mendocino Co.
Reference: Miller, 1981.

POZO FM.

Zone: CP7.
Location: Santa Barbara Co.

POZO FM. OR CAÑADA FM. (UNDIFFERENTIATED)

Zone: CP11.
Location: Santa Barbara Co. (San Miguel Island).

REPETTO FM.

Zone: CN11b/12a.
Location: Los Angeles Co.

RICES MUDSTONE (MEMBER OF SAN LORENZO FM.)

Zone: CP17/19 and CP18.
Location: Santa Cruz Co.
RINCON FM.

Zone: CP19b, CN1c, and CN1c/CN2.
Location: San Luis Obispo Co., Santa Barbara Co., and Ventura Co.

SACATE FM.

Zone: CP14a, 14b, and 15a.
Location: Santa Barbara Co.

SALTOS SHALE (MEMBER OF MONTEREY FM.)

Zone: CN3 and 4.
Location: San Luis Obispo Co.

SANDHOLDT MEMBER (OF MONTEREY FM.)

Zone: CN2, 3, and 4.
Location: Monterey Co.

SAN LORENZO FM.

Zone: CP13, 14a, 14b, 15a, 15b?, and 16?.
Location: Santa Cruz Co.

SANTA SUSANA FM.
Zone: CP5, 6, 8, 9, and 11.
Location: Ventura Co.

SODA LAKE SHALE
Zone: CN1.
Location: Ventura Co.

STADIUM CONGLOMERATE
Zone: CP14/15, CP14 or higher.
Location: San Diego Co.

"TEJON" FM.
Zone: CP13.
Location: Kern Co.

TERTIARY MUDSTONE AT PINE RIDGE
Zone: CP9.
Location: San Luis Obispo Co.

**TWO BAR SHALE**

Zone: CP14b and CP15.
Location: Santa Cruz Co.

**VACAVILLE SHALE**

Zone: CP11, 12, and 13.
Location: Solano Co.

**VAQUEROS(?) FM.**

Zone: CP19, CN1, 3, and 4.
Location: Santa Cruz Co.

**VAQUEROS FM.**

Zone: CP17/19 and CP18/19.
Location: Santa Cruz Co.
VINE HILL SANDSTONE

Zone: CP7 and CP6/8.
Location: Contra Costa Co.

WAGONWHEEL FM.

Zone: CP10.
Location: Kern Co.
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REFERENCES CITED


Barron, J. A., Bukry, D., and Poore, R. Z., 1984, Correlation of the middle Eocene Kellogg Shale of northern California:


Bukry, D., 1975, Coccolith and silicoflagellate stratigraphy,


Haq, B. U., Hardenbol, J., and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic: Science, v. 235,


Kheradyar, T., 1988, Calcareous nannofossil biostratigraphy of the Butano Sandstone, Santa Cruz Mountains, California, in Filewicz, M. V., and Squires, R. L. (editors), Paleogene


Loeblich, A. R., Jr., and Tappan, H., 1971, Annotated index and bibliography of the calcareous nannoplankton VI: Phycologia,


Squires, R. L., 1988, Rediscovery of the type locality of Turritella andersoni and its geologic age implications for West Coast Eocene strata, in Filewicz, M. V., and Squires, R. L.


