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Cover: Dr. Jean Frances DeMouthe (December 8, 1949—October 20, 2017), Collections Manager of the Geology collections at the California Academy of Sciences for more than four decades.

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Nucella demouthae, A New Species of Late Miocene Muricid Gastropod From Northern California, U.S.A.

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Nucella demouthae n. sp. is a new muricid gastropod species described from the late Miocene part of the Wilson Grove Formation in Sonoma County, central California. It is distinguished from other fossil and modern California *Nucella* by its small size and faint to moderately strong radial sculpture, and its thickened and recurved outer lip with two denticles within the interior of the aperture. To date, this fossil rocky shore predatory gastropod has been found only at Bloomfield Quarry, north of the town of Bloomfield in Sonoma County, in the lowest part of the Wilson Grove Formation, which has been dated between 9.3 and 6.2 Ma. Thus, this species is part of the malacofauna of the late Miocene "Jacalitos" California provincial molluscan stage.

Keywords: Gastropoda, Muricidae, California, Miocene

INTRODUCTION

A new species of *Nucella* (Mollusca, Gastropoda, Muricidae) was recognized by the first author in a review of invertebrate fossils of the Miocene Wilson Grove Formation (Powell et al. 2004) as *Nucella* sp., aff. *N. lamellosa* (Gmelin, 1791) and later (Powell et al. 2019) as *Nucella* n. sp. cf. *N. etchegoinensis* (Arnold, 1909). Here we describe this taxon as *N. demouthae* Powell, Roth, and Garcia, new species, in honor of the late Jean Frances DeMouthe, Senior Collections Manager of Geology at the California Academy of Sciences, who worked in dedicated service to the Academy's geological collections for 44 years.

Two other muricid gastropods are also known from the late Miocene Bloomfield Quarry exposures of the Wilson Grove Formation: fragments of an indeterminate *Ocenebrina* and *Nucella* specimens that are not well preserved, but of the latter, probably represent the present new species. In younger parts of Wilson Grove Formation two other muricids are known, *Nucella megastoma* Vermeij and Powell, 2004 (=*Acanthinucella*? n. sp. of Powell et al. 2004) and *N. trancosana* (Arnold, 1908). "*Nucella*" *imperialis* (Dall, 1909) was reported from the Salmon Creek exposures in the middle of the formation (Dickerson 1922), but its presence has not been confirmed (Powell et al. 2004; Powell et al. 2019).

GEOLOGIC SETTING

Nucella demouthae n.sp. was collected from the basal Wilson Grove Formation that outcrops in an inactive quarry, referred to as the Bloomfield Quarry (Powell et al. 2004, Powell et al. 2019) on the east side of Bloomfield Road between Bloomfield and where the road turns sharply north-northwest at the intersection of Bloomfield Road and Canfield Road in Sonoma County (Fig. 1). At Bloomfield Quarry the basal Wilson Grove Formation overlies interbedded greywacke and shale of

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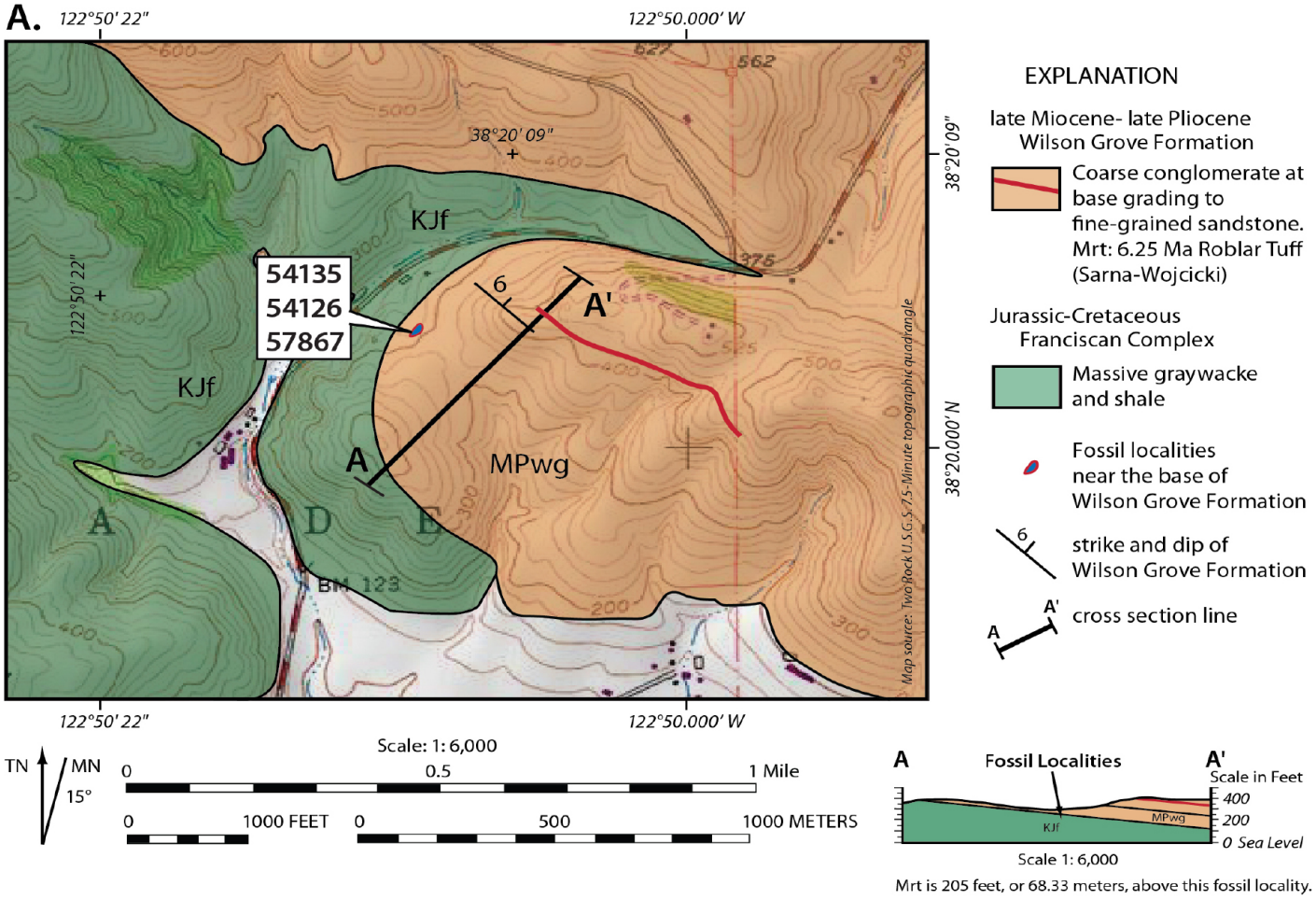

B.

Period	Epoch	Meters	Columnar Section	Description
Tertiary	late Miocene - late Pliocene Wilson Grove Formation	70 60 50 40 30 20 10 0		Roblar Tuff 6.25 Ma (A. Sarna-Wojcicki, pers. com. 1998) Massive bedded, medium to fine-grained lithic feldsarenite to feldsarenite sandstone.
Jurassic-Cretaceous	Franciscan Complex			Fossil localities CAS 54135, 54136, 57867 Basal poorly sorted, rounded, conglomerate. Clasts are all Franciscan Complex. Coarse-grained graywacke and shale

Figure 1. Index map (A) and stratigraphic column (B) showing the geology of Bloomfield Quarry, Sonoma County, California. California Academy of Sciences, Geology (CASG) fossil localities 54135, 54136, and 57867 are shown. Mrt, informally named Roblar tuff of Sarna-Wojcicki (1992); Ma, megaannum or millions of years ago. After Powell et al. (2019), courtesy of James Allen.

the Jurassic to Cretaceous Franciscan complex mélange (Bezore et al. 2003; Fig. 1) along an angular unconformity/nonconformity. The Wilson Grove section above the Franciscan complex begins with a 0.3 to 0.6 m-thick basal conglomerate containing abundant sand with pebble- to cobble-sized clasts of the Franciscan complex rock and abundant disarticulated fossil shell fragments. These basal Wilson Grove deposits contain an intertidal to shallow subtidal fauna consisting of four brachiopod, 42 mollusk (28 bivalves and 14 gastropods), six arthropods, and 25 vertebrates outlined in detail by Powell et al. (2019). The basal conglomerate is conformably overlain by about 5 m of less fossiliferous, massive-bedded, friable to locally calcite-cemented, fine- to medium-grained, very well-sorted, sandstone. This section is capped by about a meter of modern soil. As determined by Powell et al. (2019), the lower part of the Wilson Grove Formation, including Bloomfield Quarry, is late Miocene in age, and about 8 Ma based on a Sr-isotope age (Powell et al. 2019). This age conforms with an $^{40}Ar/^{39}Ar$ age determination of < 9.27 ± 0.06 Ma stratigraphically below the Wilson Grove Formation at Bloomfield Quarry and a > 6.203 ± 0.011 Ma for the Roblar tuff of Sarna-Wojcicki (1992) which overlies Bloomfield Quarry. This age range overlaps the upper part of the Tortonian and lower part of the Messinian to the Piacenzian stages of Raffi et al. (2020) and incorporates the "Jacalitos" California provincial molluscan stage (CPMS; Weaver et al. 1944) and Blancan North American Land Mammal Age.

MATERIALS AND METHODS

Eighty-seven specimens of *Nucella demouthae* were examined during a review of fossil collections at the California Academy of Sciences (including the Leland Stanford Junior University collections) for prior publications on the Wilson Grove Formation (Powell et al. 2004, Powell et al. 2019), and we re-examined them for this publication. These specimens had been collected in a single day by a field party from the California Academy of Sciences, including W. F. Barbat, R. Naidu, P. U. Rodda, and B. Roth, on October 18, 1973.

Shell measurements are defined as follows: height = greatest distance between the anterior and posterior termini; width = greatest distance between the left and right termini.

Institutional abbreviations

CASG–California Academy of Sciences, Geology Section, San Francisco; **SDSNH**–Paleontology Department, San Diego Society of Natural History.

SYSTEMATIC PALEONTOLOGY

MOLLUSCA Linnaeus, 1758
GASTROPODA Cuvier, 1795
MURICIDAE Rafinesque, 1815
OCENEBRINAE Cossmann, 1903
NUCELLA Röding, 1798

California fossil and modern *Nucella* are herein divided into three groups based on similar appearance. Group one is characterized by *N. lamellosa,* which commonly has an elongated shell and has radial sculpture. Spiral sculpture can also be present, or absent, as in smooth shells without sculpture. This group also includes *N. demouthae* n. sp., *N. etchegoinensis*, and *N. shumanensis* (Carson, 1926); the latter may be synonymous with *N. lamellosa* with further study. Group two is characterized by *N. analoga* (Forbes, 1852) with a generally smaller shell that is commonly more compressed and has weak to strong spiral sculpture. This group includes *N. angustior* Houart, Vermeij, and Wiedrick (2019), *N. canaliculata* (Duclos, 1832), *N. elsmerensis* (Grant and Gale, 1931), *N. emarginata* (Deshayes, 1839), *N. lima* (Gmelin, 1791), *N. megastoma* Vermeij and Powell, 2004, *N. ostrina* (Gould, 1852), *N. packi* (Clark, 1918), *N. rankini* Grant and Eaton in Eaton et al., 1941, *N. tokudai* (Yokoyama, 1932) [= *N. packi v. talea* Stewart (1946) *fide* Amano et al. 1993:240] and probably *N. trancosana* (Arnold, 1908). The third group is characterized by "*N.*" *collomi* (Carson, 1926) with its large adult size and strong to weak spiral sculpture, and includes "*N*". *funkeana* (Adegoke, 1969), and "*N.*" *imperialis*. This third group may require further taxonomic revision and assignment to a different genus.

NUCELLA DEMOUTHAE Powell, Roth, and Garcia, n. sp.
Figures 2-15

Nucella sp. aff. *N. lamellosa* (Gmelin, 1791), Powell et al. 2004:61, *not* Gmelin, 1791.

Nucella n. sp.? aff. *N. etchegoinensis* (Arnold, 1908), ribbed variety, Powell et al. 2019, *not* Woodring et al. 1940[1941], *not* Arnold 1909.

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Diagnosis—Distinguished from similar eastern Pacific *Nucella* by its moderate size, thickened and recurved outer lip, and faint to prominent spiral cords that are most prominent on the body whorl. Where observable, two strong denticles appear on the inside of the outer lip. This latter feature may also be found in *N. lamellosa*,

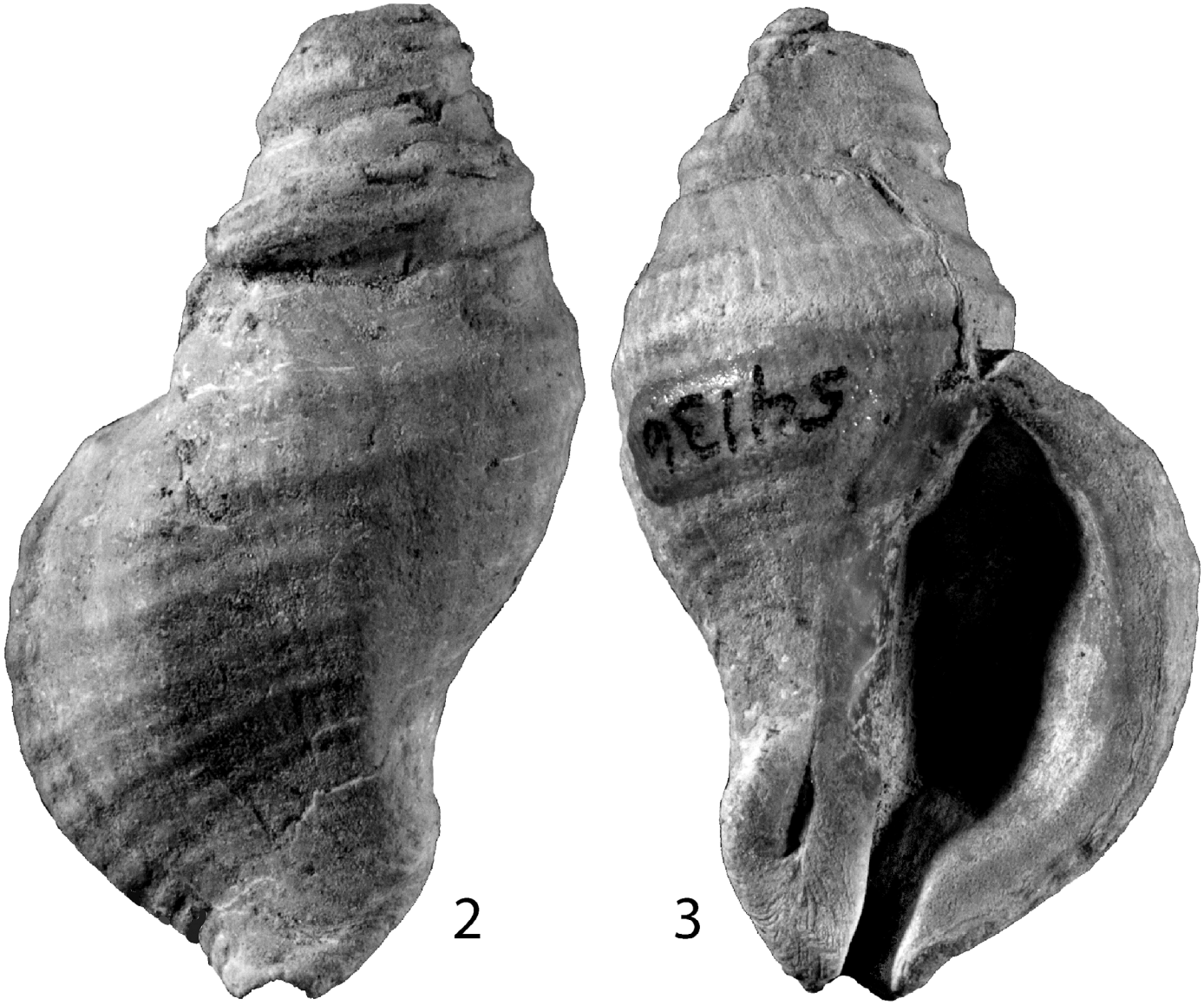


Figure 2-3. *Nucella demouthae* Powell, Roth, and Garcia n. sp. CASG holotype 73156. CASG locality 54136. Bloomfield Quarry, north of Bloomfield, Sonoma County, CA. Height 33.5 mm, width 19.2 mm. 2. Adapertural view, 3. Apertural view.

which displays none, or two to six denticles on the interior, of the apertural lip.

Holotype — CASG 73156, height 33. 4 mm, maximum width 19.5 mm.

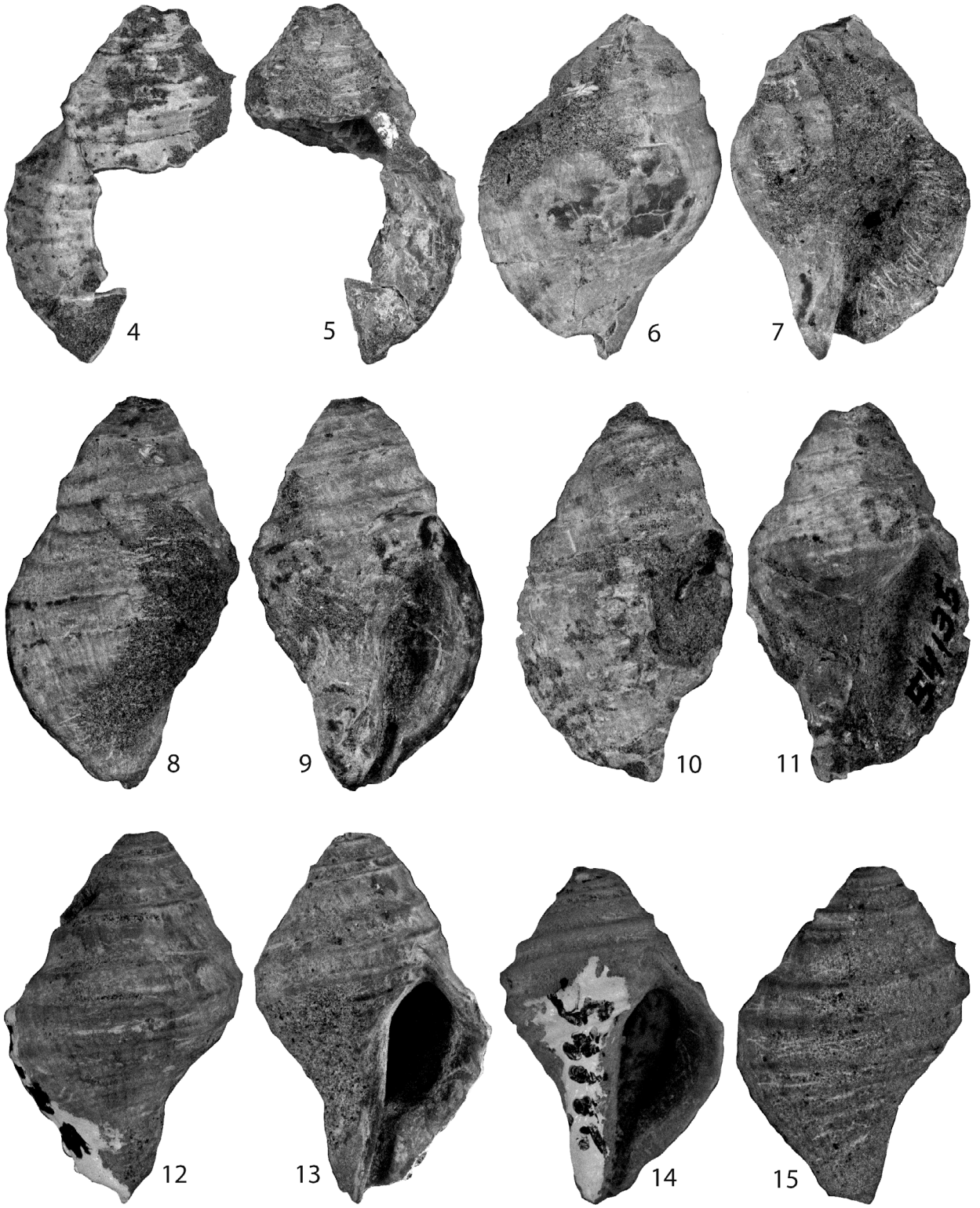
Paratype — CASG 78594, height 43.6 mm, width 24.5 mm (incomplete specimen); CASG 78595, height 36.0 mm, width 25.2 mm; CASG 78596, height 32.1 mm, width 18.9 mm; CASG 78597, height 29.8 mm, 17.5 mm; CASG 78598, height 19.2 mm, width 11.8 mm. CASG 78599, height 13.1 mm, width 8.8 mm.

Referred Specimens — CASG localities 54135 (20[66]) and 54136 (2[3]); most specimens are poorly preserved.

Occurrence — Known only from basal Wilson Grove Formation (late Miocene; "Jacalitos" CPMS) exposed at Bloomfield Quarry, north of Bloomfield, Sonoma County, California, U.S.A.

Etymology —Named for Dr. Jean Frances DeMouthe, Senior Collection Manager of Geology at CAS for many years and longtime friend.

Description — Shell of small to moderate size for the genus (8.1 to 43.6 mm height), fusiform with an elevated spire forming an apical angle of about 20°. As many as six postembryonic whorls may be present, although the



Figures 4-13. *Nucella demouthae* Powell, Roth, and Garcia n. sp., paratypes. **Mature specimens: 4, 5.** CASG 78594, height 43.6 mm, width 24.5 mm (incomplete specimen). 4. Adapertural view, 5. Apertural view. **6, 7**. CASG 78595, height 36.0 mm, width 25.2 mm. **Immature specimens: 6.** Adapertural view, 7. Apertural view. **8. 9.** CASG 78596, height 32.1 mm, width 18.9 mm. 8. Adapertural view, 9. Apertural view. **10, 11.** CASG 78597, height 29.8 mm, 17.5 mm. CASG 78598, 19.2 mm, width 11.8 mm. 10. Adapertural view, 11, Apertural view. **12, 13**. CASG 78599, height 13.1 mm, width 8.8 mm. 12. Adapertural view, 13. Apertural view. Note that immature specimens do not have a flared lip.

apex is generally broken off in most specimens. Early whorls are smooth, with two strong, unornamented spiral ribs, the first approximately midway between the sutures, the second slightly stronger, just posterior to the first; third to seventh progressively weaker spiral ribs sometimes present posterior of the main rib on the lower whorls. In larger mature specimens the spiral ribs become wider and widely spaced. Between these spiral ribs are faint, narrow, radial ribs with wide interspaces about twice as wide as the ribs. The outer lip is sharply expanded and thickened into an oblique flange, with a smooth inner margin and two teeth moderately deep in the aperture. Siphonal fasciole prominent, and siphonal canal relatively short (23% of the total length of the shell), narrow, and obliquely recurved. The columella is smooth with a rounded posterior end, which appears to extend up the adjacent exterior of the shell forming a small pseudoumbilicus. Given that these shells commonly have the aperture broken off, the following percentages are estimates. The siphon is about 23% the total length of the shell, while the aperture is about 35% of the entire shell length. Immature shells have a shorter spire than adults and do not have a recurved outer lip, but, instead, a sharp vertical lip. In addition, juvenile shells have more prominent and closely spaced spiral ribs than adult specimens.

DISCUSSION AND SPECIES COMPARISON

Names for seventeen species and eight subspecies have been attributed to the genus *Nucella* in the California Neogene (Grant and Gale 1931, Keen and Bentson 1943, Groves and Squires 2021). These species and their stratigraphic range are *Nucella canaliculata* (syn. *Thais canaliculata* var. *compressa* Dall, 1915; 10-0 Ma, Collins et al. 1996), "*N.*" *collomi** (early Pliocene, Carson 1926; 8-5 Ma, Collins et al. 1996), *N. elsmerensis** (5.3-3.6 Ma [guess based on the age of formations in Woodring et al. 1940(1941)]), *N. emarginata* (syn. *Thais emarginata* var. *projecta* Dall, 1915; late Miocene [Addicott 1978] to Holocene), *N. etchegoinensis** (late middle to middle late Miocene, Wishkahan Pacific Northwest molluscan stage, [Addicott 1983, Moore and Addicott 1987], also see discussion below), "*N*". *funkeana** (middle Pliocene [Adegoke, 1969]), "*N.*" *imperialis** (Pacific Northwest Wishkaham Stage [Addicott 1980] = "Margaritan" and lower part of the "Jacalitos" CPMS), *N. lima* (late middle to middle late Miocene, Wishkahan Pacific Northwest Tertiary molluscan stage [Addicott 1983, Moore and Addicott 1987]), *N. lamellosa* (syn. *Thais lamellosa* var. *cymica* Dall (1915), *T. l.* var. *franciscana* Dall (1915), *T. l.* var. *hormica* Dall (1915), *T. l.* var. *neptunea* Dall (1915), *T. l.* var. *sitkana* Dall (1915); probably early Pliocene to Holocene [see below]}, *N. megastoma** (late Pliocene, Vermeij and Powell 2004), *N. ostrina* (between 5.0 and 2.5 Ma, Marko et al. 2014), *N. packi** (?= *Thais (Stramonita) carrizoensis* Loel and Corey, 1932 *fide* Addicott 1970:84; lower and middle Miocene [Addicott 1970]), *N. rankini** (late Miocene [Addicott and Vedder 1963), *N. shumanensis** (lower Pliocene, Carson 1926; 8-5 Ma, Collins et al. 1996 as it was found together with *N. collomi*), *N. tokudai* (Yokoyama, 1932)* [= *N. packi* v. *talea* Stewart (1946) *fide* Amano et al. 1993:240; "Vaqueros" CPMS to Newportian Pacific Northwest Tertiary molluscan stage [early Miocene to early middle Miocene, Loel and Corey 1932, Addicott 1983, Moore and Addicott 1987]), and *N. trancosana** (Pliocene, Powell 1998). In addition, there are two species not currently known as fossils occurring in the modern northeast Pacific: *N. angustior* and *N. analoga*. Extinct species above are marked with an asterisk (*).

The species closest in appearance to *Nucella demouthae* n. sp. is *N. etchegoinensis*, which occurs in the undifferentiated Etchegoin/San Joaquin formations in the California Central Valley (Arnold 1909 [not *Thais crispatus* of Arnold, 1909, pl. XI, fig. 4; does not = *N. lamellosa* as cited by Keen and Bentson, 1943], Arnold and Anderson 1910, Woodring et al. 1940[1941]), "Etchegoin" (Pack and English 1915), Pancho Rico formations (Durham and Addicott 1965) in central California, and the Empire Formation (restricted) at Cape Blanco, Oregon (Addicott 1980, Addicott 1983). These occurrences indicating a possibly late Miocene ("Jacalitos" CPMS) to Pliocene ("San Joaquin" CPMS?) age range. Quotes are used around the biostratigraphic units (CPMSs) Etchegoin, Jacalitos, and San Joaquin to indicate that the names do not necessarily correlate with the lithostratigraphic units on which the names are based and may not be of the same age (see Powell and Houart 2021 for examples). Judging from specimens illustrated by Woodring et al. (1940[1941]) and Durham and Addicott (1965) as *N. etchegoinensis* and *Thais etchegoinensis* respectively, *N. demouthae* n. sp. is smaller in having a maximum height of 45 mm that is a bit more than half the height of illustrated specimens in Woodring et al. (1940[1941]: pl. 36, f. 1, 7; 73 and 83 mm, respectively). However, it approaches the size of the figured specimen in Durham and Addicott (1965, pl. 3, fig. 6; 59 mm). *Nucella demouthae* n. sp. can be distinguished from *N. etchegoinensis* by its thickened, broadly flattened and flaring outer lip with two strong to subdued denticles

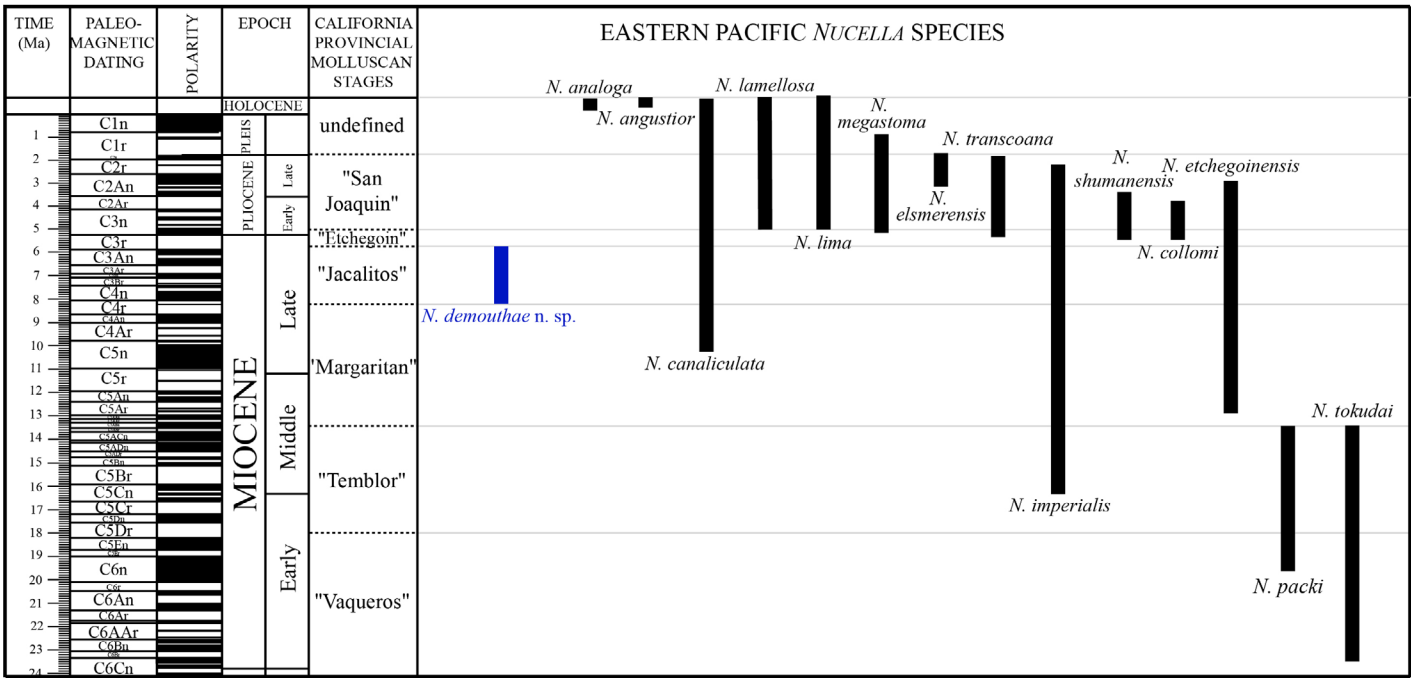


Figure 14. Stratigraphic ranges of northeastern Pacific *Nucella* spp., fossil and modern. See text for references for age range of each species.

in the aperture.

Nucella demouthae n. sp. can be difficult to distinguish from some minimally or unsculptured *Nucella lamellosa* (see Kincade 1957). However, *N. lamellosa* differs from *N. demouthae* by its larger size, broader shell, and lacking a strongly flared outer lip. Also, minimally or unsculpture *N. lamellosa* have either none or two to six, possibly seven, denticles deep on the inside of the outer lip (C. Powell, II and W. Thompson, personal observation). Those with two denticles overlap in this feature with *N. demouthae* n. sp., while the vast majority of *N. lamellosa* have more or fewer denticles and are easily distinguished.

Taxonomy within northeastern Pacific *Nucella* is complicated and in determining the evolutionary history of the genus Collins et al. (1996) and Marko et al. (2014) suggest a Tortonian International chronostratigraphic Stage age (late Miocene) for the origin of *N. lamellosa.* This is important as it represents another method for distinguishing *N. demouthae* n. sp. from *N. lamellosa* as they do not overlap in age. A closer look at the occurrences of *N. lamellosa* in rocks reported to be of Miocene age (Dall 1909, Weaver 1943, Addicott 1976, Clark 1981) uncovers complications and a Miocene origin for this species is not supported by the fossil record. Reported Miocene occurrences in California are from the Purisima Formation (Arnold 1908, Martin 1916, Allen 1945, Glen 1959, Touring 1959, Cummings et al. 1962, Perry 1993) and "Santa Margarita" Formation (Clark 1981) in Santa Cruz County, central California. However, fossil *N. lamellosa* from the Purisima Formation are actually located in the Pliocene part of the formation (C. Powell, W. Thompson, F. Perry, personal observation). Also, the age of *N. lamellosa* reported from the "Santa Margarita" Formation in the Santa Cruz Mountains (Clark 1981) is in error, as the collection also contains the Pliocene index fossil *Patinopecten healeyi* (Arnold, 1906), indicating that the formational assignment is incorrect or that the "Santa Margarita" Formation in the Santa Cruz Mountains extends into the Pliocene. Quotes are used here for the Santa Margarita Formation to indicate that it does not correlate lithologically with the type Santa Margarita Sandstone in San Luis Obispo County.

The late Miocene occurrences of *Nucella lamellosa* in Oregon are also questionable, as they are based on Dall (1909) but not Moore (1963 [1964]) reporting it from the Astoria Formation. This is curious and may indicate that Dall's identification is in error or that the specimen(s) came from some other geologic unit. The occurrence reported by Addicott (1976) in the Wishkahan Pacific Northwest provincial molluscan stage (late Miocene) cannot be verified as the specimens have not been found and were not illustrated. However, Armentrout (1981)

and Prothero et al. (2001) indicate that the Wishkahan Pacific Northwest provincial molluscan stage may be of limited stratigraphic use. Given these data we do not support Miocene age occurrences of *N. lamellosa*.

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LITERATURE CITED

Addicott, W.O. 1963. Paleotemperature inferences from late Miocene mollusks in the San Luis Obispo–Bakersfield area, California. *U.S. Geological Survey Professional Paper* 475C:C63-C68.

Addicott, W.O. 1970. Miocene gastropods and biostratigraphy of the Kern River area, California. *U.S. Geological Survey Professional Paper* 642:1-174.

Addicott, W.O. 1976. Neogene molluscan stages of Oregon and Washington. Pp. 91-115, in *Neogene Symposium*. Society of Economic Paleontologists and Mineralogy, Pacific Section, Annual Meeting San Francisco.

Addicott, W.O. 1978. Marine paleogeography and paleontology of the Salina basin during the latest part of the Miocene with notes on microfossils from near San Lucas, California. Neogene Biostratigraphy of Selected Areas in the California Coast Ranges. *U.S. Geological Survey Open-File Report* 78-446:83-90..

Addicott, W.O. 1980. Miocene stratigraphy and fossils, Cape Blanco, Oregon. *Oregon Geology* 42(5): 87-97.

Addicott, W.O. 1983. Biostratigraphy of the marine Neogene sequence at Cape Blanco, southwestern Oregon. *U.S. Geological Survey Professional Paper* 774G:G1-G20.

Adegoke, O.S. 1969. Stratigraphy and paleontology of the marine Neogene formations of the Coalinga region, California. *University of California Publications in Geological Sciences* 80:1–241.

Allen, J.E. 1945. Geology of the San Juan Bautista Quadrangle, California. University of California Ph.D. diss. Berkeley, CA.

Amano, K., G.J. Vermeij, and K. Narita. 1993. Early evolution and distribution of the gastropod genus *Nucella*, with special reference to Miocene species from Japan. *Transactions and Proceedings of the Palaeontological Society of Japan*, N.S. 171:237-248.

Armentrout, J.M. 1981. Correlation and ages of Cenozoic chronostratigraphic units in Oregon and Washington. *Geological Society of America, Special Paper* 184:137-148.

Arnold, R. 1903. The paleontology and stratigraphy of the marine Pliocene and Pleistocene of California. *Memoir of the California Academy of Sciences* III:1-420.

Arnold, R.A. 1906. Tertiary and Quaternary pectens of California. *U.S. Geological Survey Professional Paper* 47:1-264.

Arnold, R. 1908. Descriptions of new Cretaceous and Tertiary fossils from the Santa Cruz Mountains, California. *Proceedings of the U.S. National Museum* 34:345-389.

Arnold, R.A. 1909. Paleontology of the Coalinga District, Fresno and Kings counties, California. *U.S. Geological Survey Bulletin* 396:1-173.

Arnold, R., and R. Anderson. 1910. Geology and oil resources of the Coaling District, California, with a report on the chemical and physical properties of the oil by I.C. Allen. *U.S. Geological Survey Bulletin* 398:1-142.

Ashby, J.R., and J. A. Minch. 1984. The upper Pliocene San Diego Formation and the occurrence of *Carcharodon megalodon* at La Joya, Tijuana, Baja California, Mexico. Pp. 19-28 *in* J. A. Minch, J. R. Ashby (eds.). *Miocene and Cretaceous Depositional Environments of Northwestern Baja California, Mexico.* Pacific Section AAPG Guidebook 54.

Bezore, S.P., R.D. Koehler, and R.C. Witter. 2003. Geologic map of the Two Rock 7.5' quadrangle, Sonoma County, California: California Department of Conservation, California Geological Survey.

Carson, C.M. 1926. New molluscan species from the California Pliocene. *Bulletin of the Southern California Academy of Sciences* 25(2):49-62.

Clark, B.L. 1918. The San Lorenzo series of middle California. *University of California Publications, Bulletin of the Department of Geology* 11(2):45-234.

Clark, J.C. 1981. Stratigraphy, paleontology, and geology of the Central Santa Cruz Mountains, California Coast Ranges. *U.S. Geological Survey Professional Paper* 1168:1-51.

Collins, T.M., K.Frazer, A.R. Palmer, G.J. Vermeij, and W.M. Brown. 1996. Evolutionary history of northern hemisphere Nucella (Gastropoda, Muricidae): molecular, morphological, ecological, and paleontological evidence. *Evolution* 50(6):2287-2304.

Cossmann, M. 1903. *Essai de Paleoconchologie comparée.* M. Cossman, Paris. 5:1-215.

Cummings, J.C. R.M. Touring, and E.E. Brabb. 1962. Geology of the northern Santa Cruz Mountains, California. Pp. 179-220 *in* O.E. Bowen, Jr. (ed.). Geologic guide to the gas and oil fields of northern California. *Bulletin of the California Division of Mines* 181.

Cuvier, G. 1795. Second Mémoire sur l'organisation et les rapports des animaux à sang blanc, dans lequel on traite de la structure des Mollusques et de leur division en ordre, lu à la société d'Histoire Naturelle de Paris, le 11 prairial an troisième [30 May 1795]. *Magazin Encyclopédique, ou Journal des Sciences, des Lettres et des Arts* 2: 433-449.

Dall, W.H. 1909. Contributions to the Tertiary paleontology of the Pacific Coast. 1. The Miocene of Astoria and Coos Bay, Oregon. *U.S. Geological Survey Professional Paper* 59:1-278.

Dall, W.H. 1915. Notes on the species of the molluscan subgenus Nucella inhabiting the northwest coast of America and adjacent regions. *Proceedings of the U.S. National Museum* 49:557-572.

Deméré, T.A., 1983. The Neogene San Diego Basin: a review of the marine Pliocene San Diego Formation. Pp. 187-195 *in* D.K. Larue and R.J. Steel (ed). *Cenozoic Marine Sedimentation*, *Pacific Margin, U.S.A*. Pacific Section SEPM (Society of Sedimentary Geology).

Deshayes, G.P. 1839. Nouvelles espèces de mollusques, provenant des côtes de la Californie, du Mexique, du Kamtschatka et de la Nouvelle-Zélande. *Revue Zoologique par la Société Cuvierienne* 2(12):356-361.

Dickerson, R.E. 1922. Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles. *Proceedings of the California Academy of Sciences*, 4th series 11(19):527-601.

Duclos, P. L. 1832. Description de quelques espèces de pourpres, servant de type à six sections établies dans ce genre. *Annales des Sciences Naturelles* 26: 103-112.

Durham, D.L., and W.O. Addicott. 1965. Pancho Rico Formation, Salinas Valley, California. *U.S. Geological Survey Professional Paper* 524A:A1-A22.

Eaton, J.E., U.S. Grant, IV, and H.B. Allen. 1941. Miocene of Caliente Range and environs, California. *Bulletin of the American Association of Petroleum Geologists* 25(2):193-262.

Forbes E. 1852 ["1850"]. On the marine Mollusca discovered during the voyages of the Herald and Pandora, by Capt. Kellett, R.N., and Lieut. Wood, R.N. *Proceedings of the Zoological Society of London* 18: 270-274.

Groves, L.T., and Squires, R.L. 2021. Checklist of California Paleogene-Neogene marine Mollusca since Keen and Bentson (1944). *PaleoBios* 38:1-360.

Glen, W. 1959. Pliocene and lower Pleistocene of the western part of the San Francisco Peninsula. *University of California Publications in Geological Sciences* 36:147-198.

Gmelin, J.F. 1791. Systema naturae per regna tria naturae. Editio decima tertia. Lipsiae:3021-3910.

Gould, A.A. 1852. Mollusca & shells, in *United States Exploring Expedition. During the years 1838, 1839, 1840, 1841, 1842. Under the command of Charles Wilkes, U.S.N. Vol. XII*. Gould & Lincoln, Boston. 510 pp.

Grant, U.S. IV, and Gale, H.R. 1931. Catalogue of the marine Pliocene and Pleistocene Mollusca of California. *Memoir of the San Diego Society of Natural History* 1:1-1036.

Houart, R., G. Vermeij, and S. Wiedrick. 2019. New taxa and new synonymy in Muricidae (Neogastropoda; Pagodulinae, Trophoninae, Ocenebrina) from the northeast Pacific. *Zoosymposia* 13:184-241.

Keen, A.M., and Bentson, H. 1943. Check list of California Tertiary marine Mollusca. *Geological Society of America Special Paper* 56:1-280.

Kincade, T. 1957. Local races and clines in the marine gastropod *Thais lamellosa* Gmelin. A population study. The Calliostoma Co., Seattle. 75 pp.

Loel, W., and H. Corey. 1932. The Vaqueros Formation, lower Miocene of California. I. Paleontology. *University of California Publications, Bulletin of the Department of Geological Sciences* 22:275-410.

Marko, P.B., A.L. Moran, N.K. Kolotuchina, and N.I. Zaslavaskya. 2014. Phylogenetics of the gastropod genus *Nucella* (Neogastropoda: Muricidae): species identities, timing of diversification and correlated patterns of life-history evolution. *Journal of Molluscan Studies* 80(4):341-353.

Martin, B. 1916. The Pliocene of middle and northern California. *University of California Publications*, *Bulletin of the Department of Geology* 9(15):215-259.

Marko, P.B., A.L. Moran, N.K. Kolotuchina, and N.I. Zaslavskaya. 2014. Phylogenetics of the gastropod genus Nucella (Neogastropoda: Muricidae): species identities, timing of diversification and correlated patterns of life-history evolution. *Journal of Molluscan Studies* 80:341–353.

Moore, E.J. 1963[1964]. Miocene marine mollusks from the Astoria Formation in Oregon. *U.S. Geological Survey Professional Paper* 419:1-109.

Moore, E.J., and W.O. Addicott. 1987. The Miocene Pillarian and Newportian (Molluscan) States of Washington and Oregon and their usefulness in correlation from Alaska to California. *U.S. Geological Survey Bulletin* 1664A:A1-A13.

Pack, R.W., and W.A. English. 1915. Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree valleys, California. *U.S. Geological Survey Bulletin* 581D:119-160.

Perry, F.A. 1993. *Fossil invertebrates and geology of the marine cliffs at Capitola, California*. Santa Cruz City Museum, Santa Cruz. 30 pp.

Prothero, D.R., J.N. Lau, and J.M. Armentrout. 2001. Magnetic stratigraphy of the upper Miocene (Wishkahan) Empire Formation, Coos County, Oregon. Pp. 284-292 *in* D.R. Prothero (ed.). *Magnetic stratigraphy of the Pacific Coast Cenozic*. Pacific Section SEPM book 91.

Powell, C.L., II. 1998. The Purisima Formation and related rocks (upper Miocene - Pliocene), greater San Francisco Bay area, central California: review of literature and USGS collections (now housed at the Museum of Paleontology, University of California, Berkeley. *U.S. Geological Survey Open-File Report* 98-594:1-101.

Powell, C.L., II, J.R. Allen, and P.J. Holland. 2004. Invertebrate paleontology of the Wilson Grove Formation (late Miocene to late Pliocene), Sonoma and Marin Counties, California, with some observations of its stratigraphy, thickness, and structure. *U.S. Geological Survey Open-File Report* 2004-1017, 106 p.

Powell, C.L., II, R.W. Boessenecker, N.A. Smith, R.J. Fleck, S.J. Carlson, J.R. Allen, D.J. Long, A.M. Sarna-Wojcicki, A., and R.B. Guruswami-Naidu. 2019. Geology and paleontology of the late Miocene Wilson Grove Formation at Bloomfield Quarry, Sonoma County, California. *U.S. Geological Survey Scientific Investigations Report* 2019-5012, 77 p.

Powell, C.L., II, and Houart, R. 2021. *Califrapana*: a new genus proposed for California Miocene muricid previously attributed to the genus *Rapana* (Mollusca: Gastropoda: Muricidae). *PaleoBios* 38, ucmp_paleobios_521825:1-19.

Prothero, D.R., J.N. Lau, and J.M. Armentrout. 2001. Magnetic stratigraphy of the upper Miocene (Wishkahan) Empire Formation, Coos County, Oregon. Pp. 284-292 *in* D.R. Prothero (ed.). *Magnetic stratigraphy of the Pacific Coast Cenozoic*. Pacific Section SEPM book 91.

Raffi, I., B.S. Wade, H. Pälike, A.G. Beu, R. Cooper, M.P. Crundwell, W. Krijgsman, T. Moore, I. Raine, R. Sardella, and Y.V. Vernyhorova. 2020. Pp. 1141-1215 (Chapter 29 — The Neogene Period) in F.M. Gradstein, J.G. Ogg, M.D. Schmitz, and G.M. Ogg (eds.), *Geologic Time Scale 2020*, Elsevier, Netherlands.

Rafinesque, C.S. 1815. *Analyse de la Nature ou Tableau de l'Universe et des Corps Organisées.* Palermo Barravecchia. 223 pp.

Röding, P. F. 1798. *Museum Boltenianum sive Catalogus cimeliorum e tribus regnis naturæ quæ olim collegerat Joa. Fried Bolten, M. D. p. d. per XL. annos proto physicus Hamburgensis. Pars secunda continens Conchylia sive Testacea univalvia, bivalvia & multivalvia.* Trapp, Hamburg, viii + 199 pp.

Sarna-Wojcicki, A.M. 1992. Long-term displacement rates on the San Andreas fault system in northern California from the 6-Ma Roblar tuff. Pp. 29-30 *in* G. Borchardt and others (eds.). Proceedings of the second conference on earthquake hazards in the eastern San Francisco Bay area. *California Department of Conservation, Division of Mines and Geology, Special Publication* 113.

Stewart. 1946. Geology of Reef Ridge, Coalinga District, California. *U.S. Geological Survey Professional Paper* 205C:81-115.

Touring, R.M. 1959. Structure and stratigraphy of the La Honda and San Gregorio quadrangles, San Mateo County, California. Ph.D. diss. Stanford University, Stanford, CA.

Valentine, J.V. 1958. Late Pleistocene megafauna of Cayucos, California and its zoogeographic significance. *Journal of Paleontology* 32(4):687-696.

Valentine, J.W. 1980. Camalú: a Pleistocene terrace fauna from Baja California. *Journal of Paleontology* 54(6):1310-1318.

Vermeij, G.J., and C.L. Powell, II. 2004. Nucella megastoma, a new late Pliocene muricid gastropod from northern California. *Proceedings of the California Academy of Sciences*, *Fourth Series* 55(9):184-189.

Weaver, C.E. 1943 (reprinted 1958). Paleontology of the marine Tertiary formations of Oregon and Washington. *University of Washington Publications in Geology*, 5:790 pp.

Weaver, C.E. S. Beck, M.N. Bramlette, S. Carlson, B.L. Clark, T.W. Dibblee, Jr., W. Durham, G.C. Ferguson, L.C. Forest, U.S. Grant, IV, M. Hill, F.R. Kelley, R.M. Kleinpell, W.D. Kleinpell, J. Marks, W.C. Putnam, H.G. Schenck, N.L. Talliaferro, R.R. Thorup, E. Watson, and R.T. White. 1944. Correlation of the marine Cenozoic formations of western North America. *Bulletin of the Geological Society of America* 55(4):569-598.

Woodring, W.P., and M.N. Bramlette. 1950. Geology and Paleontology of the Santa Maria District, California. *U.S. Geological Survey Professional Paper* 222:1-185.

Woodring, W.P., M.N. Bramlette, and W.S.W. Kew. 1946. Geology and paleontology of the Palos Verdes Hills, California. *U.S. Geological Survey Professional Paper* 207:1-145.

Woodring, W.P., M.N. Bramlette, and K.E. Lohman. 1943. Stratigraphy and paleontology of the Santa Maria District, California. *Bulletin of the American Association of Petroleum Geologists* 27(10):1335-1360.

Woodring, W.P., R. Stewart, and R.W. Richards. 1940[1941]. Geology of the Kettlemen Hills oil field, California. *U.S. Geological Survey Professional Paper* 195:1-170.

Yokoyama, M. 1932. Tertiary Mollusca from the coalfield of Uryu, Isikari. *Journal of the Faculty of Science Imperial University of Tokyo* 3:221-247.

APPENDIX — CASG LOCALITY INFORMATION
[These localities are no longer available]

CASG Locality 54135. The lower part of a quarry is in the Franciscan Formation; the upper part is in the "Merced" Formation. The lower 0.3-0.6 m (1-2') of the "Merced" Formation is a basal conglomerate with pebbles, cobbles, and boulders of Franciscan rocks in a matrix of weakly to strongly cemented, fine to medium grained sandstone (CASG 54135). This basal conglomerate contains abundant fossils, mostly mollusks and brachiopods. Overlying the basal conglomerate is about 4-6 m (15-20') of soft, tan, fine to medium grained sandstone containing scattered fossils (mostly internal molds of mollusks) (CASG 54136). This site is located on the S side of Bloomfield Rd. 3.1 km (1.9 mi.) N 12° E of the junction of Bloomfield Road and the road that leads from the town of Bloomfield to Valley Ford, Sonoma County, California. Two Rock 7.5' quadrangle. Collected by W. F. Barbat, R. Naidu, P. U. Rodda, and B. Roth, 18 October 1973.

CASG Locality 54136. The lower part of a quarry is in the Franciscan Formation; the upper part is in "Merced" Formation. The lower 0.3-0.6 m (1-2') of the "Merced" Formation is a basal conglomerate with pebbles, cobbles, and boulders of Franciscan rocks in a matrix of weakly to strongly cemented, fine to medium grained sandstone (CASG 54135). This basal conglomerate contains abundant fossils, mostly mollusks and brachiopods. Overlying the basal conglomerate is about 4-6 m (15-20') of soft, tan, fine to medium grained sandstone containing scattered fossils (mostly internal molds of mollusks) (CASG 54136). This site is located on the S side of Bloomfield Rd. 3.1 km (1.9 mi.) N 12° E of the junction of Bloomfield Road and the road that leads from the town of Bloomfield to Valley Ford, Sonoma County, California. Healdsburg 7.5' quadrangle. Collected by W. F. Barbat, R. Naidu, P. U. Rodda, and B. Roth, 18 October 1973.