

Cenozoic Bivalve Cenozones of California, Northeastern Pacific

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Abstract

In the Cenozoic deposits of California the occurrence of the following bivalve molluscan cenozones has been established: 1 - extant species; 2 - *Fortipecten takahashii* - *Yoldia* (*Cnesterium*) *kuluntunensis*; 3 - *Acila* (*Truncacila*) *marujamensis* - *Lucinoma acutilineata*; 4 - *Mya cuneiformis* - *Acila* (*Truncacila*) *gottschei*; 5 - *Mytilus* (*Tumidimytilus*) *tichanoviichi* - *Macoma osakaensis*; 6 - *Megayoldia* (*Hataiyoldia*) *tokunagai* - *Neilonella* (*Borissia*) *sakhalinensis*; 7 - *Periploma* (*Aelga*) *besshoensis* - *Yoldia* (*Yoldia*) *kovatschensis*; 8 - *Papyridea* (*Profulvia*) *harrimani* - *Ciliatocardium asagaiense*; 9 - *Megayoldia* (*Portlandella*) *watasei* - *Yoldia* (*Nampiella*) *takaradaensis*; 10 - *Nuculana* (*Saccella*) *gabbii* - *Corbula* (*Cuneocorbula*) *formosa*; 11 - *Lucina washingtonensis* - *Nuculana* (*Saccella*) *alaeformis*. The established cenozones are compared with the standard Californian molluscan stages (Addicott, 1972), resulting in age reductions for some of the Neogene stages. The lower part of the Vaqueros molluscan stage is regarded as late Oligocene.

Key words: biostratigraphy, cenozones, clustering, bivalve molluscs, Paleogene, Neogene, California.

1. Introduction

In California, identification of Cenozoic regional stages by molluscs has a long tradition (Arnold, 1906; Schenck and Kleinpell, 1936; Weaver et al., 1944; Corey, 1954; Durham, 1954; Agedoke, 1969; Addicott, 1972, 1973, 1977, 1979, 1981; Kleinpell, 1980; Armentrout and Echols, 1981; Marincovich, 1984a, b; Moore, 1984a; Moore and Addicott, 1987). However, efforts to correlate those stages with Cenozoic molluscan assemblages of the northeastern Pacific (e.g. Armentrout et al., 1984) are fraught with considerable difficulty.

The contemporary North Pacific zoogeographical region is subdivided into three independent subregions: Japan-Manchurian, Beringian and Oregon-Sitkan. Their separation

began in the late Paleogene (Kafanov, 1991). The subregions are characterized by much specific, generic and even family endemism, and the degree of this endemism increases as one moves upward in the Cenozoic section (Addicott, 1976; Chinzei, 1978). The notable endemism of Neogene molluscan faunas of the Pacific coast of North America was reported previously by Smith (1919) and Clark (1921). A considerable difference between the faunas of the northwestern and northeastern Pacific is also observed in other animal groups. For example, Patterson (1981) concluded that the western North American fish fauna shows no particular transoceanic relationships. A low number of common extinct species presents an important problem for widespread transoceanic correlations.

Also, due to the fact that on the eastern coast of the North Pacific the zonal biogeographic differences are smoothed out compared to the western coast (Sverdrup et al., 1942; Hall, 1964), the biostratigraphic boundaries are less clearly expressed on the eastern coast. Addicott (1972)

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determined that some Californian Miocene formations are not superimposed on one another, but rather are facies of the same age.

Using cluster analysis procedures for bivalve assemblages, Kafanov and Ogasawara (2003a) have preliminarily distinguished 11 cenozones for the Paleogene and Neogene of the northwestern Pacific: 1 - extant species; 2 - *Fortipecten takahashii* - *Yoldia* (*Cnesterium*) *kuluntunensis*; 3 - *Acila* (*Truncacila*) *marujamensis* - *Lucinoma acutilineata*; 4 - *Mya cuneiformis* - *Acila* (*Truncacila*) *gottschei*; 5 - *Mytilus* (*Tumidimytilus*) *tichanoviitchi* - *Macoma osakaensis*; 6 - *Megayoldia* (*Hataiyoldia*) *tokunagai* - *Neilonella* (*Borissia*) *sakhalinensis*; 7 - *Periploma* (*Aelga*) *besshoensis* - *Yoldia* (*Yoldia*) *kovatschensis*; 8 - *Papyridea* (*Profulvia*) *harrimani* - *Ciliatocardium asagaiense*; 9 - *Megayoldia* (*Portlandella*) *watasei* - *Yoldia* (*Nampiella*) *takaradaiensis*; 10 - *Nuculana* (*Saccella*) *gabbii* - *Corbula* (*Cuneocorbula*) *formosa*; 11 - *Lucina washingtonensis* - *Nuculana* (*Saccella*) *alaeformis*. Using the data for other stratigraphically useful groups of organisms (diatoms, foraminifers, spores and pollen), as well as absolute dating, the authors traced the distribution of these cenozones in Sakhalin (Kafanov, 2003; Kafanov and Ogasawara, 2003b), Kamchatka, Koryak Upland and Chukotka (Kafanov and Ogasawara, 2004) as well as in Hokkaido, northern Japan (Kafanov et al., 2005), and to correlate them with the geochronological scale.

It is of interest to analyze the distribution of the cenozones in the Cenozoic deposits of California, whose Cenozoic bivalve faunas are well studied. Another reason for the analysis of the distribution of bivalve cenozones in California is that in recent years the age of the Cenozoic formations of the Russian Far East has been revised substantially (Gladenkov et al. eds., 1998; Gladenkov, 2001, 2003), and the existing schemes of molluscan correlation of Cenozoic deposits of the North Pacific (e.g. Armentrout et al., 1984) need revision. Unfortunately, due to the above reasons, Californian molluscan assemblages have rarely been used to form clusters with assemblages known in the northwestern Pacific. Therefore, the obtained results are

preliminary in character.

2. Material and methods

The species lists for Cenozoic formations of California were compiled on the basis of the comprehensive revisions by Moore (1983, 1984b, 1987, 1988, 1992, 2003a, b). These publications include high-quality photographs of all type specimens and original descriptions, which excluded possible misidentification of species. Species lists for the Russian Far East were compiled from Kafanov et al. (1999, 2000, 2001). Clusters of associated species for each formation are named "assemblages". Only valid species and subspecies were considered. The total number of these from California is 705.

The determination of molluscan cenozones (sensu International Stratigraphic Guide; Salvador ed., 1994) was made by assemblage clustering using Ward's method (1963). This method differs from numerous other methods (giving in our case similar results) in that it uses dispersion analysis for evaluating the distance between clusters, minimizing the intraclass scatter between the objects of clustering. A similar approach was used recently by Mandic and Steininger (2003) for the Eggenburgian (Lower Miocene) molluscan biostratigraphy of north-eastern Austria.

"Percent disagreement" between assemblages was calculated. This measure is particularly useful if the data for dimensions included in the analysis are categorical (presence/absence) in nature (Cheetham and Hazel, 1989). The distance is computed as: distance (x, y) = (number of x, y_i)/i. Since clustering results are largely dependent on species richness (Kafanov, 1994; Kafanov et al., 2004), the subsequent clustering analysis used bivalve assemblages containing not fewer than 10 species.

3. Results and discussion.

The left-hand and right-hand groups of clusters are distinguished sharply in the similarity/difference dendrogram of the bivalve assemblages (Fig. 1). The first group incorporates assemblages that include a considerable number of extant species and are conventionally attributed

to the Neogene. The assemblages of the right-hand group of clusters almost completely lack extant species and are conventionally attributed to the Paleogene.

Let us first consider the assemblages of the first group (Table 1). In the assemblages of the San Diego, Pico, Niguel, San Pedro and Fernando Formations, the number of extant species in common surpasses the number of extinct species in common. There are no extant species in common with the Pomyr Formation of Sakhalin and the Enemten Formation of western Kamchatka. However, the Ust'-Limimteveyams kaya Suite of Karaginsky Island, eastern Kamchatka, has a molluscan fauna including *Chlamys* (C.) cf. *hastata* (Sowerby, 1843), a Recent species, not recognized previously in the northwestern Pacific, as well as *Fortipecten hallae* (Dall, 1921), positively identifying the *Fortipecten takahashii* - *Yoldia* (*Cnesterium*) *kuluntunensis* cenozoone of the northwestern Pacific. Thus, the five formations mentioned above can be confidently compared with cenozoone 2, most likely corresponding to the "San Joaquin" and "Etchegoin" molluscan stages of California. The assemblages of the Wildcat Group and the associated Rio Dell Formation contain a small proportion (32 %) of extinct species, and are attributed to the uppermost part of cenozoone 2 (*Acila* (*Truncacila*) *empirensis* Howe, 1922, *Chlamys* (*Swiftipecten*) *palmeleei palmeleei* (Dall, 1898), *Keenocardium lispum* (Keen, 1954), *Lucinoma acutilineata* (Conrad, 1849), *Mactromeris brevirostrata* (Packard, 1915) and *Nanaochlamys nutteri* (Arnold, 1906)). This agrees with the data given by Faustman (1963).

For the assemblages of the Purisima, Merced and Etchegoin Formations, the species in common with the Ermanov and Etolona Formations of western Kamchatka is *Lucinoma acutilineata* (Conrad, 1949), and that in common with the Etolona Formation is *Macoma vanvlecki* Arnold, 1910. This permits a comparison between the assemblages of these three formations and cenozoone 3 (*Acila* (*Truncacila*) *marujamensis* - *Lucinoma acutilineata*), and attributes the "Etchegoin" and "Jacalitos" molluscan stages of

California to cenozoone 3. The "Jacalitos" stage can be recognized by the lowest stratigraphic occurrence of split-ribbed *Patiniopecten* (Addicott, 1977), of which *Patiniopecten* (*Blanckenhornia*) *healeyi* (Arnold, 1906) appears in the Purisima and Merced Formations. Addicott (1977) considered the age of the "Jacalitos" stage to be late Miocene. With respect to the molluscs, in the Etchegoin stage several zones of local significance can be distinguished (Adegoke, 1969).

Of the extant species in common to the Monterey and Santa Margarita Formations and the San Pablo Group (Neroly F., Cierbo and Briones Sandstones), the faunal list of the Ilyin Formation of western Kamchatka includes *Macoma* (?*Rexithaerus*) cf. *andersoni* Clark, 1915, and the list of the Yaponskikh Kamney Suite of eastern Kamchatka includes *Spisula* (*Pseudocardium*) cf. *densata* (Conrad, 1856). This may indicate the assignment of assemblages of the Monterey and Santa Margarita Formations and the San Pablo Group to cenozoone 4 (*Mya cuneiformis* - *Acila* (*Truncacila*) *gottschei*) and its correspondence to the Margaritan molluscan stage of California.

The assemblages of the Imperial, Saugus, Santa Barbara, Towsley, Pancho Rico, and San Joaquin Formations, Tahana Member (of Purisima Formation), Ohlson Ranch Formation, Foxen Mudstone, and Careaga Formation, Lomita Marl Member (of San Pedro Formation), and the Capistrano, Neroly, Cierbo, Briones, Sobrante and San Ramon Sandstones and the upper part of the Temblor Formation form a rather coherent cluster in the middle portion of the dendrogram in Fig. 1. No extinct species in common were distinguished for all these formations, although according to the distribution of separate characteristic species, these formations should be attributed to cenozoones 2-5, corresponding to Miocene-Pliocene deposits.

On the similarity-difference dendrogram (Fig. 1), the assemblages of the Vaqueros and Temblor Formations, having a great number of extinct species in common (Table 1), come very close to the assemblages of the typical Paleogene formations of California (right-hand

Table 1. Main cluster descriptions for Neogene bivalve assemblages of California (Fig. 1).

Formations incorporated	Common extinct species	Common extant species	Proportion of extant species, %
San Diego + Pico+ Niguel + San Pedro + Fernando	<i>Anadara (A.) trilineata</i> (Conrad, 1854), <i>Argopecten callidus</i> (Hertlein, 1925), <i>Argopecten invalidus</i> (G.D.Hanna, 1924), <i>Chlamys (Ch.) opuntia</i> (Dall, 1898), <i>Chlamys (Swiftopecten) palmeleei</i> (Dall, 1898), <i>?Dendrostrea vespertina</i> (Conrad, 1845), <i>Flabellipecten stearnsii</i> (Dall, 1878), <i>Glycymeris (Axinola) grewingki</i> Dall, 1909, <i>Hinnites giganteus</i> (Gray, 1825), <i>Leporimetus obesa</i> (Deshayes, 1855), <i>Lituyapecten dilleri</i> (Dall, 1901), <i>?Lopha veatchii</i> (Gabb, 1866), <i>Lucina (Lucinisca) nuttallii</i> (Conrad, 1837), <i>Lucinoma acutilineata</i> (Conrad, 1848), <i>Lyropecten cerrosensis</i> (Gabb, 1866)	<i>Acila (Truncacila) castrensis</i> (Hinds, 1843), <i>Anadara (Larcinia) camuloensis</i> (Osmont, 1905), <i>Argopecten circularis</i> (Sowerby, 1835), <i>Axinopsida serricata</i> (Carpenter, 1864), <i>Chama arcana</i> Bernard, 1976, <i>Chlamis (Ch.) hastata</i> (Sowerby, 1843), <i>Chlamys (Ch.) jordani</i> (Arnold, 1903), <i>Chlamys (Ch.) rubida</i> (Hinds, 1844), <i>Codacia (Epilucina) californica</i> (Conrad, 1837), <i>Crassinella pacifica</i> (C.B.Adams, 1852), <i>Dallocardia quadragenarium</i> (Conrad, 1837), <i>Diplodonta orbella</i> (Gould, 1851), <i>Gari (Gobraeus) californica</i> (Conrad, 1837), <i>Gari (Gobraeus) fucata</i> (Hinds, 1845), <i>Here excavata</i> (Carpenter, 1857), <i>Macoma (Rexithaerus) indentata</i> Carpenter, 1864, <i>Mactromeris catilliformis</i> (Conrad, 1867), <i>Megangulus bodegensis</i> (Hinds, 1845), <i>Monia macrochisma</i> (Deshayes, 1839), <i>Nuculana (Saccella) taphria</i> (Dall, 1896)	> 40
Purisima + Merced + Etchegoin	<i>Chlamys (Swiftopecten) palmeleei</i> (Dall, 1898), <i>Clinocardium meekianum</i> (Gabb, 1866), <i>Hinnites giganteus</i> (Gray, 1825), <i>Lucinoma acutilineata</i> (Conrad, 1848), <i>Mactromeris albaria</i> (Conrad, 1848), <i>Nanaochlamys nutteri</i> (Arnold, 1906), <i>Patinopecten (Blanckenhornia) healeyi</i> (Arnold, 1906)	<i>Acila (Truncacila) castrensis</i> (Hinds, 1843), <i>Chlamis (Ch.) hastata hastata</i> (Sowerby, 1842), <i>Chlamys (Ch.) hastata hericius</i> (Gould, 1860), <i>Chlamys (Ch.) rubida</i> (Hinds, 1844), <i>Clinocardium nuttallii</i> (Conrad, 1837), <i>Macoma inquinata</i> (Deshayes, 1855), <i>Mactromeris hemphillii</i> (Dall, 1894), <i>Yoldia (Kalayoldia) cooperi</i> Gabb, 1865	32.0
Vaqueros + Temblor	<i>Amussiopecten vanvlecki</i> (Arnold, 1907), <i>Chlamys branneri</i> (Arnold, 1906), <i>Chlamys hertleini</i> (Loel et Corey, 1932), <i>Ciliocardium reedi</i> (Loel et Corey, 1932), <i>Crassatella granti</i> (Wiedey, 1928), <i>?Crassostrea engleknyi</i> (Hertlein, 1928), <i>Crenomytilus mathewsonii</i> (Gabb, 1866), <i>Diplodonta buwaldana</i> Anderson et Martin, 1914, <i>Felaniella harfordi</i> (Anderson, 1905), <i>Here excavata</i> Carpenter, 1857), <i>Litorhadia astoriana</i> (Henderson, 1920), <i>Lucinoma acutilineata</i> (Conrad, 1849), <i>Lyropecten</i>	<i>Diplodonta orbella</i> (Gould, 1851), <i>Here excavata</i> Carpenter, 1857)	6.8

	<i>miguelensis</i> (Arnold, 1906), <i>Lyropecten vaughani</i> (Arnold, 1906), <i>Macoma</i> (<i>Rexithaerus</i>) <i>panzana</i> Wiedey, 1928, <i>Macrochlamys magnolia</i> (Conrad, 1857), ? <i>Mactromeris sectoris</i> (Anderson et Martin, 1914), <i>Miltha sanctaerucis</i> (Arnold, 1909), <i>Oppenheimopecten sanctaerucis</i> (Arnold, 1906), <i>Pacipecten andersoni subandersoni</i> (Loel et Corey, 1932), <i>Pteria hertleini</i> Wiedey, 1928, <i>Semele morani</i> Anderson et Martin, 1914, <i>Solena</i> (<i>Plectosolen</i>) <i>gravidus</i> (Clark, 1918), <i>Spisula</i> (<i>Pseudocardium</i>) <i>densata</i> (Conrad, 1856), <i>Spisula</i> (<i>Pseudocardium</i>) <i>panzanum</i> (Loel et Corey, 1932), " <i>Tellina</i> " <i>wilsoni</i> Anderson et Martin, 1914, <i>Vertipecten kernensis</i> (Hertlein, 1925), <i>Vertipecten perrini</i> (Arnold, 1906)		
Monterey + Santa Margarita + San Pablo Group (Neroly F., Cierbo and Briones Sandstones)	<i>Lyropecten crassicardo</i> (Conrad, 1857), <i>Lyropecten estrellanus</i> (Conrad, 1857), <i>Macoma</i> (? <i>Rexithaerus</i>) <i>andersoni</i> Clark, 1915, <i>Mactromeris albaria</i> (Conrad, 1848), <i>Pacipecten discus</i> (Conrad, 1857), <i>Spisula</i> (<i>Pseudocardium</i>) <i>densata</i> (Conrad, 1856)	<i>Felaniella parilis</i> (Conrad, 1848), <i>Here exavata</i> (Carpenter, 1857), <i>Lucinoma annulata</i> (Reeve, 1850), <i>Mactromeris catilliformis</i> (Conrad, 1867)	11.5
Saugus + Santa Barbara + Towsley + Pancho Rico	<i>Cyclocardia californica</i> (Dall, 1903)	<i>Chlamys</i> (<i>Ch.</i>) <i>jordani</i> (Arnold, 1903), <i>Gari</i> (<i>Gobraeus</i>) <i>fucata</i> (Hinds, 1845), <i>Lucinoma annulata</i> (Reeve, 1850), <i>Nuculana</i> (<i>Sac-cella</i>) <i>taphria</i> (Dall, 1896)	> 60.0

group of clusters). The Temblor Formation contains *Delectopecten peckhami* (Gabb, 1869), which is widely distributed in the Oligocene Amaninskaya, Gakkhinskaya and Viventekskaya Suites of western Kamchatka, as well as in the Machigarskaya, Arakayskaya, Takaradayskaya, Gastellovskaya, Kholmiskaya and Tumskaya Suites of Sakhalin. *Ciliatocardium reedi* (Loel and Corey, 1932), described from the "Vaqueros-Temblor transition zone" and in common to the Vaqueros and Temblor Formations, is reported in the Snatol'skaya and Aluginiskaya Suites of western and eastern Kamchatka. This leads us to assume an Oligocene age for all of the Vaqueros Formation and for a considerable portion of the Temblor Formation (the assemblages of its upper part in Fig. 1 form a coherent cluster with the assemblages of the Sobrante and Briones Sandstones)

and to attribute the bivalve assemblages present in them to cenozones 6 (*Megayoldia* (*Hataiyoldia*) *tokunagai* - *Neilonella* (*Borissia*) *sakhalinensis*) and 5 (*Mytilus* (*Tumidimytilus*) *tichanovitchi* - *Macoma osakaensis*).

The Oligocene age of the Vaqueros Formation was discussed previously by Schenck (1935a-c) in connection with problems of the Aquitanian Stage of Europe. Addicott (1979) attributed the Vaqueros (?) Formation at the Indians, Santa Lucia Range, entirely to an Oligocene unnamed molluscan stage. Making his analysis by benthic foraminifers, Lagoe (1984) assigned the Temblor Formation an Oligocene-early Miocene age and included the entire Vaqueros Formation in the Oligocene. The $^{87}\text{Sr}/^{86}\text{Sr}$ data (Keller et al., 1995) also confirm the Oligocene age of the Vaqueros Formation. The Saucian-Zemorrian foraminifera

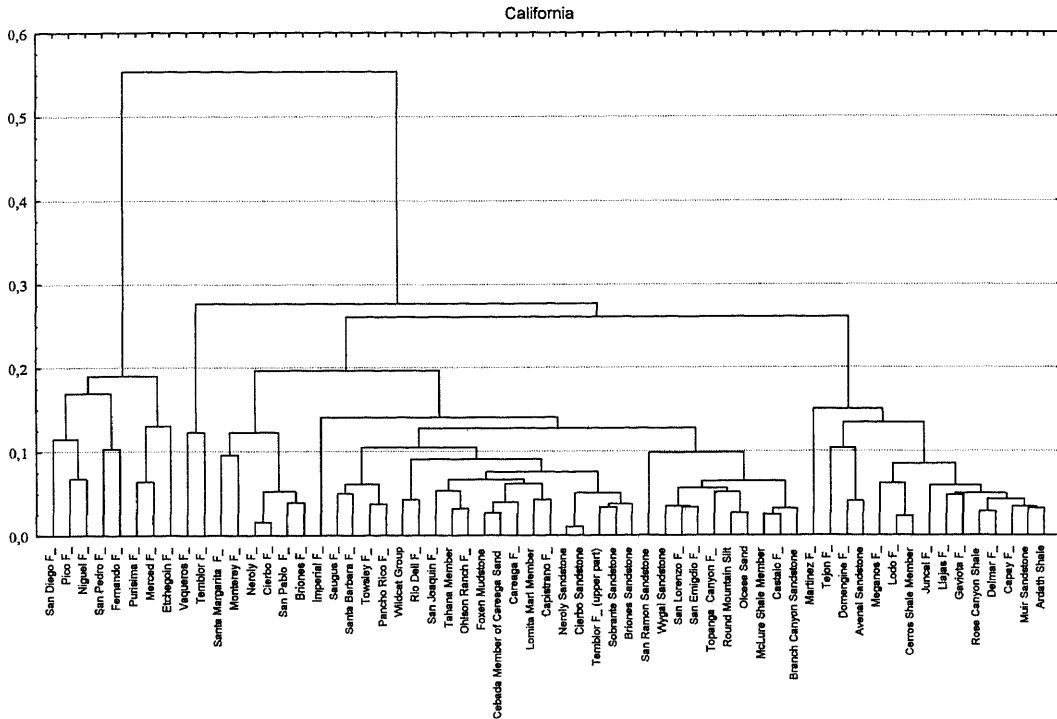


Fig. 1. Similarity dendrogram of molluscan assemblages of California by species composition of Bivalvia. The “percent disagreement” is given on the axes of ordinates herein and on Fig. 2.

feral boundary, which falls within the middle part of the “Vaqueros” molluscan stage, has been dated by K-Ar at about 22.5 Ma (Turner, 1970). Prothero and Donohoo (2001) and Prothero and Hoffman (2001) showed that the Sespe/Vaqueros contact is late Oligocene (28 Ma) in Ventura County, while the same Sespe/Vaqueros contact in Orange County is early Miocene (17 Ma), based on mammalian biostratigraphy and magnetostratigraphy. The Vaqueros Formation in San Luis Obispo County (Soda Lake Shale Member, Caliente Range) is about 22-23 Ma, based on foraminifers and magnetostratigraphy. Thus, the base of the Vaqueros is grossly time-transgressive over almost 11 million years, and it is inappropriate to use the old “Vaqueros Stage” of earlier authors. The lower Temblor Formation (type section of the Zemorrian in the Temblor Range) is also very incomplete and time-transgressive (Prothero and Resseguie, 2001). The Wygal

Sandstone and Cymric Shale are about 32-33 Ma (earliest Oligocene) followed by an 8-million-year-unconformity, then the upper part of the section (lower Santos Shale Member, Agua Sandstone Bed) is 23-25 Ma (latest Oligocene-earliest Miocene). Benthic foraminifera, which have usually been assigned to mollusc-bearing units in California, show the same results for the Saucesian-Zemorrian boundary (Barron and Isaacs, 2001). Thus, the Paleogene/Neogene boundary may be assumed conventionally to lie in the middle part of the Vaqueros molluscan stage (Berggren and Van Couvering, 1974; Ryan et al., 1974; Addicott, 1977; Addicott and Poore, 1982).

Assemblages of the Wygal Sandstone and the San Lorenzo and San Emigdio Formations have two extinct species in common: *Mactromeris ramonensis ramonensis* (Packard in Clark, 1915) and *Yoldia (Kalayoldia) tenuissima* Clark, 1918. *Spisula packardi* Dickerson, 1917, reported from

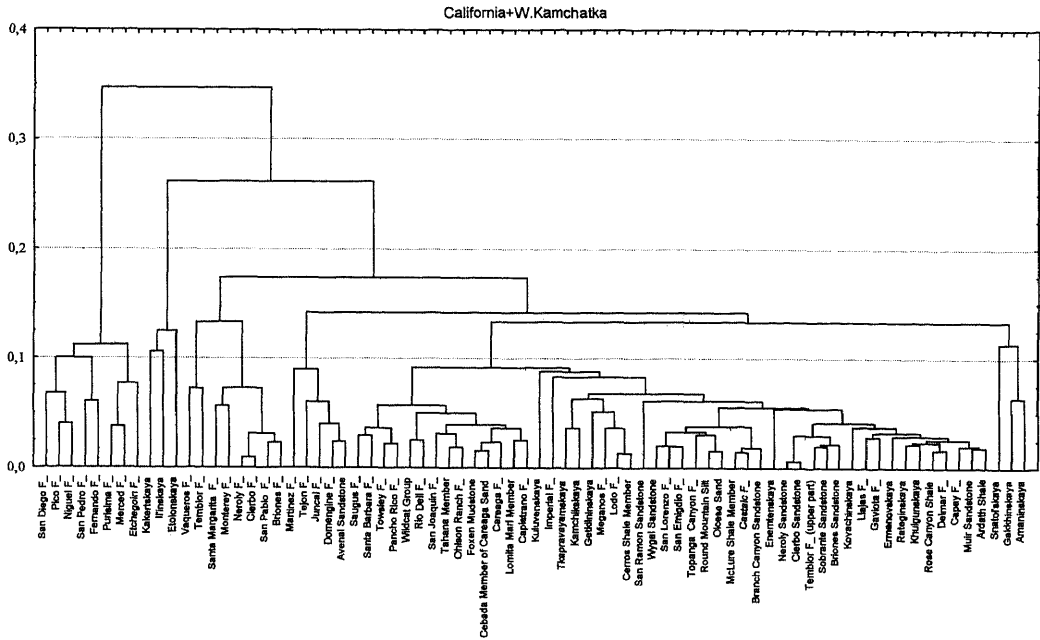


Fig. 2. Similarity dendrogram of molluscan assemblages of California and western Kamchatka by species composition of Bivalvia.

San Emigdio Formation, is also known in the Niklekuyul'skaya Suite of western Kamchatka; *Acila (Acila) gettysburgensis* (Reagan, 1909), reported in the San Lorenzo Formation, is also known in the Arakayskaya, Takaradayskaya, Kholm'skaya, and the lower part of the Nevel'skaya and Daekhuriinskaya Suites of Sakhalin. Therefore, the first two assemblages are most likely attributed to cenozoone 7 (*Periploma (Aelga) besshoensis* - *Yoldia (Yoldia) kovatschensis*), and the assemblage of the San Emigdio Formation to cenozoone 8 (*Papyridea (Profulvia) harrimani* - *Ciliatocardium asagaiense*).

The assemblages of the Juncal, Lajas, Gaviota, Delmar and Capay Formations, Rose Canyon Shale, Muir Sandstone and Ardath Shale have a high level of similarity and are close to those of the Rateginskaya and Khulginskaya Suites in western Kamchatka (Fig. 2). The Rateginskaya Suite corresponds to cenozones 8 and 9 and is attributed to the Kovachin Formation. The Khulginskaya Suite corresponds

to cenozoone 11 and is attributed to the lower part of the Yuzhnoilipin Formation. Thus, the age of all the 8 California formations under study listed here may be assigned to the Eocene-Paleocene (cenozones 8-11).

Assemblages of the Tejon and Domengine Formations and Avenal Sandstone are characterized by a large number of species in common: *Acila (Truncacila) decisa* (Conrad, 1855), *Acutostrea idriaensis* (Gabb, 1869), *Brachidontes (Brachidontes) cooperi* Moore, 1983, *Claibornites diegoensis* (Dickerson, 1916), *Donax latus* Gabb, 1869, *Glycymeris (Glycymerita) sagittata* (Gabb, 1869), *Glyptoactis (Claibornicardia) domendinica* (Vokes, 1939), *Nemocardium (Nemocardium) linteum* (Conrad, 1855), *Nuculana (Saccella) gabbii* (Conrad, 1869), *Pachecoia (Pachecoia) hornii hornii* (Gabb, 1864), *Pteria pellucida* (Gabb, 1864), *Schedocardia breweri* (Gabb, 1864) and *Spondylus carlosensis* Anderson, 1905. By the presence of *Nuculana gabbii* (Conrad, 1869) they may definitely be attributed

Epoch	Series	Cenozoone	Formations in California	Provincial molluscan stages*
Q		1		
Pliocene		2	San Diego, Pico, Niguel, San Pedro, Fernando	"San Joaquin" "Etchegoin"
	Upper	3	Etchegoin, Purisima, Merced	"Jacalitos"
Miocene	Middle	4	Monterey, Santa Margarita, San Pablo Group	"Margaritan" "Temblor"
	Lower	5	Temblor	"Vaqueros"
	Upper	6	Vaqueros	
Oligocene	Lower	7	Wygol, San Lorenzo	Unnamed (Addicott, 1973)
	Upper	8 9	San Emigdio	Refugian
Eocene	Middle and Lower	10	Tejon, Domengine, Avenal Sandstone	"Tejon" "Transition" "Domengine" "Capay"
Paleocene			Meganos, Lodo	Meganos
		11	Martinez	Martinez

Fig. 3. Distribution of bivalve cenozones in Neogene and Paleogene deposits of California. *Provincial molluscan stages are named - for Neogene according to Addicott (1972, 1977), for Paleogene according to Weaver et al. (1944); Refugian stage distinguished mainly by benthic foraminifers (Schenck and Kleinpell, 1936). Bivalve cenozones: 1 - extant species; 2 - *Fortipecten takahashii* - *Yoldia* (*Cnesterium*) *kuluntunensis*; 3 - *Acila* (*Truncacila*) *marujamensis* - *Lucinoma acutilineata*; 4 - *Mya cuneiformis* - *Acila* (*Truncacila*) *gottschei*; 5 - *Mytilus* (*Tumidimytilus*) *tichanovitchi* - *Macoma osakaensis*; 6 - *Megayoldia* (*Hataiyoldia*) *tokunagai* - *Neilonella* (*Boris-sia*) *sakhalinensis*; 7 - *Periploma* (*Aelga*) *besshoensis* - *Yoldia* (*Yoldia*) *kovatschensis*; 8 - *Papyridea* (*Profulvia*) *harrimani* - *Ciliatocardium asagaiense*; 9 - *Megayoldia* (*Portlandella*) *watasei* - *Yoldia* (*Nampiella*) *takaradaensis*; 10 - *Nuculana* (*Saccella*) *gabbii* - *Corbula* (*Cuneocorbula*) *formosa*; 11 - *Lucina washingtonensis* - *Nuculana* (*Saccella*) *alaeformis*.

to cenozone 10 (*Nuculana (Saccella) gabbii* - *Corbula (Cuneocorbula) formosa*).

The assemblages of the Meganos and Lodo (including Cerros Shale Member) Formations have the following species in common: *Acila (Truncacila) decisa* (Conrad, 1855), *Crassatella lillisi* (Dickerson, 1916), *Glycymeris (Glycymerita) major* (Stanton, 1896), *Ledina fresnoensis* (Dickerson, 1916), *Nucula (Nucula) cooperi* Dickerson, 1913, *Pachecoa (Pachecoa) hornii elusa* (Clark and Woodford, 1927) and *Schedocardia breweri hartleyensis* (Clark and Woodford, 1927). These assemblages form a common cluster with the assemblages of the Tkpravayamskaya, Kamchikskaya and Getkilninskaya Suites of western Kamchatka (Fig. 2) at a high level of similarity. In particular, species common to the Meganos and Lodo Formations and the Getkilninskaya Suite are *Acila (Truncacila) decisa*, *Ledina fresnoensis* and *Nucula (Nucula) cooperi*. Therefore, the assemblages of the Meganos and Lodo Formations can be confidently compared with cenozone 11 (*Lucina washingtonensis* - *Nuculana (Saccella) alaeformis*).

The assemblages of the Martinez Formation have the following species in common with the assemblages of the Tejon and Domengine Formations and Arenal Sandstone: *Acila (Truncacila) decisa*, *Acutostrea idriaensis*, *Nemocardium (Nemocardium) lintheum*, *Nuculana (Saccella) gabbii* and *Schedocardia breweri*. However, because of the presence of *Nuculana (Saccella) alaeformis* (Gabb, 1869), they are confidently attributed to cenozone 11.

As a whole this cenozone correlation scheme (Fig. 3) only differs from the known sequence of molluscan stages (Addicott, 1972, 1977, 1979, 1981) in some age reduction of the Neogene stages.

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