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FOSSIL RECORDS OF CERTAIN SCHOOLING FISHES OF THE CALIFORNIA CURRENT SYSTEM

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Otoliths, vertebrae, teeth, and other fish remains are abundant in southern California Plio-Pleistocene deposits of marine origin, and in coastal Indian middens. Unfortunately, fossil and artifact recovery techniques employed by most paleontologists and archaeologists fail to reveal any but the largest fish remains, so not much has been known about the fish faunas that existed off our shores in the past. When recent experiments showed me how inadequate the "perusal-by-eye" technique is for recovering fossil otoliths (Fitch, 1966), and how poor the otolith yield and species content are when only coarse screenings are examined (Fitch, ms), I resampled numerous sites and subjected the fossiliferous matrix to more refined methods of washing, screening, and sorting.

As a result of these experiments, I have established a routine wherein field samples are screened through three sieves (2, 1, and 0.5 mm, U.S. Standard Sieve Series) that fit one into the other "piggy-back" style. After soaking my field sample in a tub of water, I place several handfuls of the saturated "dirt" solution into the top (largest mesh) sieve, submerge all three in a second tub of water to within one half inch of the top of the upper sieve, and filter the mixture by gently rotating and shaking the submerged screens. Before dumping the contents of each screen onto newspaper to dry, I clean the contained residue by rinsing it with water from a running hose.

When the sample is dry, I screen the coarsest material through ¼-inch (0.63 cm) mesh to remove large shells, rocks, bone fragments, and similar items. The residue retained by the ¼-inch (6.3 mm) screen can be checked by eye for the rare shark tooth or large otolith it might contain. I examine all remaining material by spreading a spoonful at a time in a flat dish with raised edges, and systematically searching through this residue with a pair of forceps while using a binocular miscroscope at six magnifications. By having washed the samples through three sieves, the particles are graded by size and the task of searching through the material under the microscope is greatly simplified.

Using these techniques of washing, screening and sorting, I have gleaned upwards of 100,000 otoliths, teeth and other fish remains from an assortment of Indian middens and Pleistocene and Pliocene deposits. To date, these remains have represented 167 species (23 elasmobranchs and 144 bony fishes), more than one-fourth of the marine fish fauna recorded from California during modern times. This statistic takes on even greater significance when one considers that otoliths of about 75 species of teleosts known to our waters are too small to be retained by 30 mesh screens (the finest mesh screen I use), and otoliths of possibly another 75 species are not likely to be found because these fishes are inhabitants of rocky substrate —a habitat type that is generally lacking in the fossil record. Then, too, many species have been noted only once or twice from our shores in more than a century of recorded history; unless they were considerably more abundant during earlier epochs, their recognizable remains are not likely to turn up in a ton or two of fossilized dirt.

Because fossil remains represent only death associations, they are not useful for making population estimates; however, finding the remains of a given species in a particular bed, horizon, or exposure is fairly good evidence the species was living in the area at the time of deposition—especially if it can be demonstrated that material in the bed has not arrived there from reworking of older deposits. Although radiologic dating techniques have improved greatly since carbon-14 measurements were first made, we still have not reached the stage where the geochronology of the Pleistocene (or older epochs) can be demonstrated in units smaller than 10,000 years. Regardless of this limitation, all information regarding fossil assemblages has application to modern-day problems, especially those involving ecology, evolution, dispersal, catastrophies, faunal anomalies, etc.

While this report deals generally with all fish remains I have found in Indian middens and Plio-Pleistocene deposits, specific details will be given for only six species: Pacific herring, *Clupea pallasi*; northern anchovy, *Engraulis mordax*; Pacific hake, *Merluccius productus*; Pacific sardine, *Sardinops caeruleus*; Pacific mackerel, *Scomber japonicus*; and jack mackerel, *Trachurus symmetricus*. These six species are schooling fishes, inhabit the California Current System, are of great economic importance or of potential importance, and all but one (*Merluccius*) can be caught abundantly with purse seine gear.

FISH REMAINS IN INDIAN MIDDENS

Although remains found in Indian middens do not constitute "true" fossils in a strict interpretation, they often are called "sub-fossils," and they usually offer our only link between present-day faunas and events, and those of the Pleistocene. In coastal California, many Indian middens cover a time span rang-

ing from 300 to 7,000 years before the present (B.P.). Many of these sites are relatively undisturbed, and for remains found in these, radiocarbon dates furnish fairly accurate (± 100–250 years) information as to time of habitation.

Fish remains, especially otoliths, can arrive in a midden any of four ways, at least. Most, apparently are from food fishes the Indians caught and carried to the cooking or cleaning site. When the discarded remains of these fishes deteriorate, many otoliths, teeth, vertebrae, scales, and other hard parts remain relatively unchanged and become a permanent record in the midden. Remains of small prey species undoubtedly were discarded in the stomachs of fish, mammals, birds, and other fish-eating predators the Indians had harvested. The otoliths of these often can be recognized because they show some indication of digestive action, but so would otoliths from fish that had been eaten elsewhere by a scavenging gull and had passed through its digestive tract while it was foraging in the Indian garbage dump. Finally, some otoliths, shark teeth, stingray stings, and other items were prized by the Indians as ornaments, tools, weapons, etc., and these occasionally were lost, discarded or interred in their middens.

Of perhaps 20 publications reporting fish remains in California's coastal middens, only four (Follett, 1963a, 1963b, 1965; Fitch, 1967a) mention species of direct concern to this report. One of these sites, the Conejo Rock shelter in Ventura County (Ven-69) yielded 16 vertebrae identified as being from *Sardinops caeruleus* and 6 vertebrae from *Scomber japonicus* (Follett, 1965).

Two sites (LAn-52 and LAn-227), both in Los Angeles County, yielded remains only of *Scomber* from among my select six species. In the Arroyo Sequit midden (LAn-52) the recognized *Scomber* remains consisted of two dentary bones and 21 vertebrae (Follett, 1963a); whereas, at the Century Ranch site (LAn-227), they consisted of two vertebrae (Follett, 1963b). Fitch (1967a) reported an anchovy, *Engraulis mordax*, otolith from an Orange County excavation (Ora-190).

During the past several years, I have examined over 18,000 otoliths, plus an assortment of teeth, vertebrae, and miscellaneous fish remains from four coastal Indian middens (Table 1), and have identified more than 50 species from these middens that had been fed upon by the Indians or by some predator they had harvested. Perhaps 100 additional otoliths have been identified for various investigators who obtained them from other sites. One of these additional otoliths, collected by Carl L. Hubbs, Scripps Institution of Oceanography, at a La Jolla site, was from a jack mackerel, but none of the others represented a species of concern to this report.

Fish Remains from Ven-3

Ven-3, a Chumash Indian Village site at the ocean's edge in the city of Ventura, was partially excavated by a group of archaeologists in 1965. Their routine screening of 13 "standard" pits (each 1 by 2 by 0.7 m) and 2 control pits (each 1 by 1 by 0.7 m) yielded 7,357 otoliths from 10 species of fish and quantities of other fragments from several additional species. Eleven of these 15 pits were double-screened, which consisted of rescreening with $\frac{1}{8}$-inch (3.2 mm) mesh the residue that passed through $\frac{1}{4}$-inch (6.3 mm) mesh. Since these "coarse" screens would miss the remains of many fish species, two small samples of midden material (perhaps totaling 0.5 m^3) were sent to me for processing by my three-sieve technique. The residue from these samples yielded 408 otoliths representing an additional 9 species, and

TABLE 1

NUMBERS OF OTOLITHS OF SELECT SPECIES IN INDIAN MIDDENS AND PLIO-PLEISTOCENE DEPOSITS OF SOUTHERN CALIFORNIA

	300–7,000?				100,000–2,000,000? Pleistocene							3,000,000–10,000,000? Pliocene		
	Indian Middens				PV Sand[1]			SP Sand[2]		Tms Pt Slt[3]		Lom Marl[4]	Pico Fm[4]	
Species	Ven 3	Ven 168	SBa 1	Ora 190	700 Blk	500 Blk	Del Rey	Ven Fwy	Mfl St	Tms Pt	Bts Rd	Mrl Cn	Npt Msa	Dntn LA
Engraulis mordax	30	14	64	1	8	7	262	70	80	4	2	49	6	23
Sardinops caeruleus	--	1	6	--	--	--	--	--	--	--	--	--	--	--
Merluccius productus	--	--	--	--	--	1	35	--	--	20	6	55	427	561
Trachurus symmetricus	--	--	--	--	--	--	3	--	3	1	1	46	24	31
Clupea pallasi	--	--	--	--	--	--	--	1	29	5	1	8	1	3
Scomber japonicus	--	--	--	--	--	--	--	--	--	--	--	15	3	4
Total otoliths (all species)	7,765	10,342	145	2	282	662	2,591	1,200	2,746	2,601	1,243	24,299	5,103	4,285
Total species (teleosts)	19	12	9	2	20	31	47	40	30	53	37	83	55	48

[1] Columns 5, 6, and 7 involve sites at: 500 block North Pacific Avenue, San Pedro; 700 block North Pacific Avenue, San Pedro; and Playa del Rey—representing Palos Verdes sand, late Pleistocene (warm oceanic temperatures and shallow depths).
[2] Columns 8 and 9 involve sites on the Ventura Freeway, Ventura; and at Miraflores Street, San Pedro—representing San Pedro sand, early Pleistocene (cold oceanic temperatures and shallow depths).
[3] Columns 10 and 11 involve sites at Timms Point, San Pedro; and on Bates Road, Santa Barbara County—representing Timms Point silt, early Pleistocene (cold oceanic temperatures and relatively deep water).
[4] Columns 12, 13, and 14 involve sites at: Miraleste Canyon, San Pedro; Newport Mesa, Orange County; and downtown Los Angeles—representing Lomita Marl and Pico Formation, Pliocene (cold oceanic temperatures and relatively deep water).

teeth of 7 more elasmobranchs. In all, remains of 45 fish species were identified from the Ven-3 site (Fitch, ms).

Although no otoliths of hake and Pacific mackerel were found, there were many jaw fragments and vertebrae from these two species, and lateral line scutes from *Trachurus symmetricus* were also present. All of the anchovy otoliths (Table 1) were among the 408 sagittae removed from the two special samples I processed. This extensive midden has been covered with asphalt and made into a parking lot since these investigations were carried out.

Fish Remains from Ven-168

Ven-168, a Chumash Village site beside the Ventura River 7 miles inland from the coast, was excavated intensively by archaeologists during 1967. Although 10,327 otoliths from eight species of bony fishes were found during the routine dig, 10,238 of these were from the white croaker, *Genyonemus lineatus*. The 231 fish teeth found at the same time were from 10 elasmobranchs and 3 additional teleosts. Since all of these remains had been retrieved with $\frac{1}{4}$- and $\frac{1}{8}$-inch mesh screens, a small sample of washed residue from a 30-mesh screen was sent to me for microscopic examination. This material was from a 3.6-foot (110 cm) deep control pit.

Because of time limitations, I examined residue from only 2 of the 11 subsamples sent me; these were from near mid-depth and the bottom of the control pit (30 to 40, and 100 to 110 cm levels). This material yielded otoliths of two additional teleosts and teeth of five additional elasmobranchs. Anchovy otoliths were at both levels, eight in material taken 11.81 to 15.75 inches (30 to 40 cm) beneath the surface, and six in the lowermost 3.94 inches (10 cm) of the midden. In addition, one broken sardine otolith turned up in the 30 to 40 cm stratum. All of these otoliths showed signs of erosion from digestive action, indicating they had been in the stomach of some predatory species caught by the Indians. Ven-168 was destroyed by freeway construction subsequent to these investigations.

Fish Remains from SBa-1

SBa-1 covers much of the top and sides of a hill overlooking the ocean at Rincon Point on the southern boundary of Santa Barbara county. In places, midden material is 8 to 10 feet (2.4 to 3.0 m) deep, indicating site occupancy of several thousand years. An archaeological group from UCLA was investigating this site during 1966 and 1967, and during this time I picked up about 200 pounds of midden dirt from their discard piles. There is no way to correlate the samples I obtained with any given depth. Broken mollusk shells were extremely abundant throughout the site, but fish remains were rather sparse in the material I examined, and presumably throughout this midden. The total otolith yield from the 200-pound field sample (145) represented only nine species, and 123 of these were from only two: *Engraulis mordax* (64) and *Genyonemus lineatus* (59). Six of the otoliths were from small sardines which apparently had been in the stomachs of predatory species, because all showed signs of digestive action. Teeth and vertebrae of an additional 12 to 15 kinds of teleosts and elasmobranchs were also found, but none was abundant. SBa-1 was almost completely destroyed (hauled away for fill dirt) during freeway construction in late 1967.

Fish Remains from ORA-190

Ora-190 is a small site about 2 miles southeast of Newport Bay and a similar distance inland from Corona del Mar in Orange County. The inhabitants of this site did not seem to be as marine oriented as were those of the three sites discussed previously. Very few objects of marine origin (e.g., mollusk shells) were found here during excavations in 1966 by members of the Pacific Coast Archaeological Society. I was supplied with a 6-inch square column of dirt from one of their excavation pits, and when I had finished washing, screening, and sorting this material, I had found identifiable remains from five elasmobranchs and six teleosts (Fitch, 1967a). One of the two otoliths I found was from an anchovy that appears to have arrived at the site in the stomach of some predator the Indians had carried there. The otolith was in the 6- to 12-inch (15.24 to 30.48 cm) horizon of a 30-inch (76.2 cm) deep pit, which was the maximum depth of Ora-190. This site appears destined to be covered by a housing tract in the not-too-distant future.

FISH REMAINS IN PLEISTOCENE DEPOSITS

Highly-fossiliferous marine Pleistocene deposits are constantly being exposed in southern California coastal localities through natural erosion as well as by housing and road construction, cut-and-fill projects, quarrying, tunneling, and a multitude of other digging activities of man. Many sites of historical interest are covered up or carried away each year, but concurrently many others are exposed for varying periods. The mollusks and foraminifera contained in long-exposed deposits usually have been investigated rather intensively, and many other groups of invertebrates have been the object of serious study, but fish remains, other than large shark and ray teeth, generally have been overlooked. In my studies, I have concentrated upon recovering fish remains, and toward this end, I have removed and examined a few pounds to possibly a ton of fossiliferous matrix from each of a dozen or more Pleistocene outcrops in southern California.

Geologists and paleontologists generally agree that our youngest marine Pleistocene is the lowest of a dozen terraces that can be seen in any profile study of Palos Verdes hill which lies between San Pedro and Redondo Beach, and at numerous other coastal and insular localities. This terrace corresponds to deposits that have been termed Palos Verdes sand and an age of 95,000 to 130,000 years B.P. recently has been determined for these sediments by Fanale and Schaeffer (1967) who also assign an age of 330,000 to 420,000 to the oldest (12th) terrace in this series. These 12 terraces comprise the late Pleistocene in southern California.

Two early Pleistocene deposits (San Pedro sand and Timms Point silt) apparently complete the marine Pleistocene in the Los Angeles area, and the San Pedro sand is unanimously accepted as being the younger of the two. No ages have been determined for either, however.

I have found otoliths from four of the six species this report is concerned about, but remains of *Sardinops* and *Scomber* are absent in the Pleistocene, in-so-far as it has been sampled (Table 1).

Fish Remains from the Palos Verdes Sand

The Palos Verdes sand represents a lengthy period when the ocean waters that bathed our shores were considerably warmer than they are at present. Many of the mollusks reported from these beds are locally extinct southern forms, and six of the fishes that left their remains have not been taken north of about Cedros Island or Magdalena Bay during modern times, and still others rarely are seen off California even during several years of warmer than average water temperature (Radovich, 1961).

Three of 12 exposures of Palos Verdes sand that I have examined have yielded recognizable remains, mostly otoliths and teeth, from 57 species of teleosts and 18 elasmobranchs. A few of these have been from lanternfishes, macrourids, and other offshore-living species, but most of the fishes represent assemblages that normally are found in depths no greater than 10 to 12 fathoms (18.3 to 22 m) over sandy or sandy-mud bottoms (Fitch 1964, 1966). Otoliths of *Engraulis mordax* were abundant at Playa del Rey, and were present at two San Pedro sites I sampled (500 and 700 blocks, North Pacific Avenue). The Playa del Rey deposit also yielded otoliths from *Merluccius* and *Trachurus,* but except for a single hake otolith, these two species were absent at San Pedro (Table 1). The deposit in the 700 block, North Pacific Avenue, San Pedro, was both exposed and hauled away during construction of the access to the Vincent Thomas Bridge, while the deposit two blocks south of there and on the opposite side of Pacific Avenue is no longer accessible because it undermines private property. Fossiliferous material can still be found at the Playa del Rey site, but fossils have been excavated at this locality for nearly four decades and the exposure is badly depleted.

Fish Remains from the San Pedro Sand

The fish remains I have recovered from two widely separated deposits of San Pedro sand represent a fauna such as one would encounter north of Point Conception today. Two of the species found in these deposits (night smelt, *Spirinchus starksi,* and Pacific tomcod, *Microgadus proximus*) have not been noted south of Point Conception during modern times, and several others have centers of distribution well to the north of the two sites that I sampled.

One of these exposures at the base of a cliff in the 600 block, Miraflores Street, San Pedro, yielded identifiable remains of 10 elasmobranchs and 30 teleosts (Fitch, 1967b). *Engraulis, Clupea,* and *Trachurus* otoliths were among the 2,746 sagittae that I found, but there was no evidence of *Merluccius, Sardinops,* or *Scomber.* The other deposit I sampled (1.1 miles upcoast from the Ventura River in a freeway cut) yielded fair numbers of *Engraulis* otoliths and one from *Clupea,* but none from the other four species being considered here (Table 1). The 1,200 otoliths from this deposit represented 40 species; an additional 3 species were identified from teeth. In all, 55 species (45 teleosts and 10 elasmobranchs) were identified from the two sites.

The Miraflores Street deposit at San Pedro is doomed by the impending extension of the Harbor Freeway during 1968, but the exposure of San Pedro sand in the freeway cut near Ventura should be accessible for many years to come.

Fish Remains from the Timms Point Silt

The type locality for the Timms Point silt at San Pedro has been extensively sampled for mollusks, foraminifera, and a few other groups, but the only published report of teleost remains from this deposit is a plate showing six fish otoliths in a publication on foraminifera (Bagg, 1912). My investigations of Timms Point silt at the type locality have yielded otoliths, teeth and other remains representing 53 species of bony fishes and 9 of elasmobranchs (Fitch, 1968), while an exposure in a road cut on Bates Road near its juncture with state highway 150 in Santa Barbara County has turned up an additional 18 species of teleosts. Only 30 of the 2,370 otoliths from the Timms Point (San Pedro) site were from fishes of concern to this report, but these were from four species: *Clupea, Engraulis, Merluccius,* and *Trachurus.* The Bates Road deposit yielded otoliths from the same four species, but in even smaller numbers (Table 1).

The many remains from lanternfishes, melamphaids, and deep-water scorpaenids are indicative of deposition at depths of 400 to 600 feet (122 to 183 m) or more, and the locally-extinct northern forms (*Ammodytes hexapterus, Atheresthes stomias, Lyconectes aleutensis, Malacocottus zonurus, Microgadus proximus,* and *Theragra chalcogramma*) are reasonably good proof that ocean temperatures were a great deal colder than today at the same latitude.

Most outcrops of Timms Point silt in the San Pedro area have been buried under houses, streets, etc., and behind retaining walls, but the Bates Road deposit and some near Newport Beach should be accessible for additional sampling for a number of years.

FISH REMAINS IN PLIOCENE DEPOSITS

Historically, the Lomita marl has been reported as the oldest marine Pleistocene in southern California (Valentine, 1961; Woodring, Bramlette, and Kew, 1946; and others), and many contemporary invertebrate paleontologists who are familar with the formation accept this viewpoint (Warren Addicott, pers. commun.). Additionally, it has been argued that the basal part of the Villafranchian Stage of Europe (lateral equivalent of the Calabrian Stage which is basal Pleistocene) has an older radiometric age determination (3.3 million years B.P.) than the estimate

of 3.04 million years B.P. reported for the Lomita marl by Obradovich (1965).

My work with fossil fish otoliths, and intensive sampling of the Lomita marl by personnel from the Los Angeles County Museum of Natural History since 1964 have provided substantial evidence that the Lomita marl is in fact the youngest marine Pliocene unit in southern California (Kanakoff and McLean, 1966; Kanakoff, pers. commun.; Fitch, unpubl. data). The younger age estimate for the Lomita marl (compared to the age that has been assigned the basal Pleistocene of Europe) could have resulted from a vagary of the relatively unproven radiometric techniques involved. Duplicate tests on a given piece of material often have yielded age estimates that are at greater variance than the 300,000 years in the present case. No age estimates are available for either the Pico formation, or the San Diego formation, two other well-known components of the southern California marine Pliocene.

Fish remains were abundant in all Pliocene deposits that I examined, and the species these represent, with one exception, are still extant. I have found otoliths of five of the six species of concern to this report, but not one *Sardinops* sagitta is represented among the nearly 34,000 Pliocene otoliths I have identified from three deposits (Table 1).

FISH REMAINS IN PLIOCENE DEPOSITS

Although one of the best known (historically) Lomita marl deposits (Hilltop Quarry, San Pedro) was covered by a housing project in the early 1940's, an exposure in the bottom of a canyon just north of there has yielded the richest fossil fish fauna known to the Pliocene of North America. The 24,299 otoliths I have recovered from this site represent a minimum of 82 species (Table 1), while more than 15 kinds of elasmobranchs are identifiable among the 575 shark, skate, and ray teeth. Possibly one ton of fossiliferous matrix was washed, screened, and sorted to obtain these remains.

The fish fauna is comprised of many mesopelagics, a few bathypelagics and a half-dozen kinds of locally extinct northern forms, in addition to an assortment of species that is typical of 20- to 50-fathom (36.6 to 91.5 m) depths at the latitude of San Pedro today. The several thousand lanternfish (family Myctophidae) otoliths I found here are from at least 11 species, but the most abundant single species among the more than 82 kinds of teleosts was *Physiculus rastrelliger* (2,424 otoliths), a deep-water, bottom-dwelling morid (family Moridae).

This deposit has been exposed for more than two years, but the canyon 100 yards west of the site is being filled, and a similar fate apparently is in store for the remainder of the canyon in the not-too-distant future.

Fish Remains from the Pico Formation

A deposit uncovered in 1967 during housing construction on the mesa south of upper Newport Bay appears to represent the Pico formation, but this assumption is based upon the fish fauna and may not hold up when additional evidence has been carefully examined. Approximately 500 pounds of fossiliferous matrix I dug at this site yielded over 5,100 otoliths and 1,200 elasmobranch teeth. These remains represented more than 70 species (55 teleosts), but except for *Merluccius productus* (427 otoliths), sagittae of the six species of concern to this report were not abundant (Table 1). As with the Lomita marl deposit, otoliths of *Physiculus* (1,387) were more numerous than those of any other single species.

Material from one other bed of the fossiliferous Pico formation was examined and yielded quantities of teleost otoliths (4,285) and a small collection of elasmobranch teeth (182). This material was salvaged during excavation of a sub-basement for a multi-storied building in downtown Los Angeles. *Merluccius* otoliths (561) comprised more than 13 percent of the total yield (Table 1), but unlike the Newport Mesa deposit not many *Physiculus* sagittae (33) were present.

SPECIES ACCOUNTS

The sagittae of the six species covered in this report are easy to distinguish from all other species including their closest relatives, once one knows what characters are diagnostic and whether certain observed differences are valid. Generally, the configuration of the sulcus (the groove, channel, imprint, or pitted area on the inner face of each sagitta) in conjunction with one or more other features will serve to identify the otolith to family (e.g., the typically-shaped two-part sulcus, cockscomb-like arrangement of spines along the ventral margin, and broadly-oval outline in lateral aspect will distinguish engraulid otoliths). Once an otolith has been recognized at the family level, numerous other features are important in distinguishing genera and species, but one must study lengthy series of otoliths before he can evaluate the variability he observes, and make accurate identifications.

In order to assist various investigators concerned with food-habit, age, and other studies wherein otoliths may be encountered or utilized, I have prepared a dichotomous key, which in conjunction with the figures (Figure 1a through h) should permit rapid identification of native (the introduced *Alosa* and *Dorosoma* are not included) engraulid and clupeid genera regardless of their state of digestion or fragmentation.

Key to Otoliths of Californian Engraulid and Clupeid Genera

1. A series of short spines radiating from ventral margin of otolith; dorsal and ventral contours strongly arched, otolith oval in broad outline; rostrum (anteriorly projecting "nose-piece" ventral to sulcus) short, comprising one-fourth or less of total otolith length _____Engraulidae, 2
   Ventral margin of otolith incised but never spinose; dorsal and ventral contours straight (parallel), or nearly so; rostrum long, comprising one-

third or more of total otolith length _____ _____Clupeidae, 4

2. Otolith more than twice as long as high, highest point posterior to center of otolith; anterodorsal margin concave; posterior termination relatively sharp, never evenly rounded _____ *Engraulis*
   Otolith less than twice as long as high, highest point at mid-length; anterodorsal margin convex; posterior end evenly rounded _____ 3
3. Antirostrum (anteriorly projecting portion above sulcus) distinct, sharply pointed; rostrum pointed; ostium (mouth or front part of sulcus) more than one-half as high as otolith at that point _____ _____ *Cetengraulis*
   Antirostrum indistinct or absent; rostrum rounded; ostium about one-third as high as otolith at that point _____ *Anchoa*
4. Sulcus extending to posterior margin of otolith slightly above centerline; posterior end of otolith notched where cauda (tail or posterior part of sulcus) reaches margin _____ *Clupea*
   Sulcus fails to reach posterior margin of otolith, turning slightly downward in those genera where it almost reaches end of otolith, never terminating above center-line; posterior end of otolith never notched, although profile invaginated or concave below center-line in some genera _____ 5
5. Sulcus straight for entire length, cauda terminating well inside posterior rim which is evenly rounded _____ 6
   Sulcus curves slightly downward posteriorly, terminating just inside margin; posterior end with an overhanging bulge above cauda, never evenly rounded _____ 7
6. Rostrum equal to height of otolith; antirostrum about twice as long as post-caudal field (area between end of cauda and posterior rim of otolith) _____ *Opisthonema*
   Rostrum short, about one-half as long as otolith height; antirostrum as long as post-caudal field, or nearly so _____ *Harengula*
7. Rostrum long, equal to nearly one-half length of otolith; antirostrum distinct; dorsal and ventral margins of otolith nearly parallel, dorsal margin smooth or nearly so; overhanging postero-dorsal bulge tapering to a rounded point _____ *Sardinops*
   Rostrum short, equal to about one-third of otolith length; antirostrum indistinct; dorsal margin sloping upward posteriorly, usually deeply notched above end of ostium (mouth or anterior part of sulcus); postero-dorsal bulge broadly and evenly rounded _____ *Etrumeus*

Scombrid sagittae have been discussed and illustrated by Fitch and Craig (1964), who found it is impossible to confuse otoliths of *Scomber* with those of any other fish. The otoliths of *Merluccius* (Figure 3f) are equally distinctive, but those of *Trachurus* could be mistaken for *Decapterus* except for one unvarying character—the angle of flexure of the cauda. In *Trachurus,* the cauda bends downward near its posterior extremity at a 45° angle, whereas in *Decapterus* it bends at a 90° angle. This is especially apparent in an examination of the ventral rim of the cauda (Figure 2). No other carangid otolith (of the nine other species noted from California) resembles the sagittae of *Trachurus* and *Decapterus* sufficiently to create a problem.

Anchovies

Otoliths of *Engraulis mordax* were present in every Indian midden (4), Pleistocene (7), and Pliocene (3) deposit that I investigated during the past several years (Table 1). They comprised as much as 44 percent of the total otolith yield in one Indian midden (SBa-1), 10 percent in one Pleistocene deposit (Playa del Rey), and one-half of one percent in one Pliocene deposit (Pico formation).

Beds of Palos Verdes sand and San Pedro sand represent deposition in shallow water, the former (P. V. sand) during a period when ocean temperatures were considerably warmer off southern California than at present, and the latter (S.P. sand) when ocean temperatures were colder. On the other hand, Timms Point silt fossils reflect deposition in relatively deep water (±600 feet) during a time when ocean temperatures were colder than normal.

The three Pliocene deposits (Table 1) were laid down at depths and temperatures similar to those of the Timms Point silt.

Obviously, *Engraulis* has been present off our coast during warm as well as cold periods, and in both shallow and deep areas for upwards of 12 million years, at least.

Herring and Sardines

Clupea otoliths were present in all of the Pleistocene and Pliocene sites that represented deposition during periods when ocean temperatures were colder than at present. They were not found in the deposits that reflected warm oceanic conditions (Table 1), and none was recovered from the four Indian middens examined.

No *Sardinops* otoliths were found in any Pleistocene or Pliocene deposit regardless of depth or temperature, but two of the four Indian middens that I investigated yielded recognizable fragments of sardine otoliths (Table 1, Figure 3c). All seven of these otoliths were from small fish (yearlings or younger), none was entire, and all were somewhat eroded as if they had been in the digestive tracts of predators the Indians had caught. Follett (1965) identified 16 vertebrae recovered at a Ventura County site (Ven-69) as having come from *Sardinops caeruleus.*

Pacific Mackerel

No Pacific mackerel otoliths were found in any of the Pleistocene exposures that I investigated regardless of depth or temperature at the time of deposition, but all three Pliocene deposits yielded their sagittae (Table 1). Otoliths that are indistinguishable from those of *S. japonicus* are present in Miocene deposits near Bakersfield (±25 million years old), so Pacific mackerel are not "new" to our coast. Absence of their remains in Pleistocene deposits could reflect a reduced population during that period, but there is no proof that this was the case.

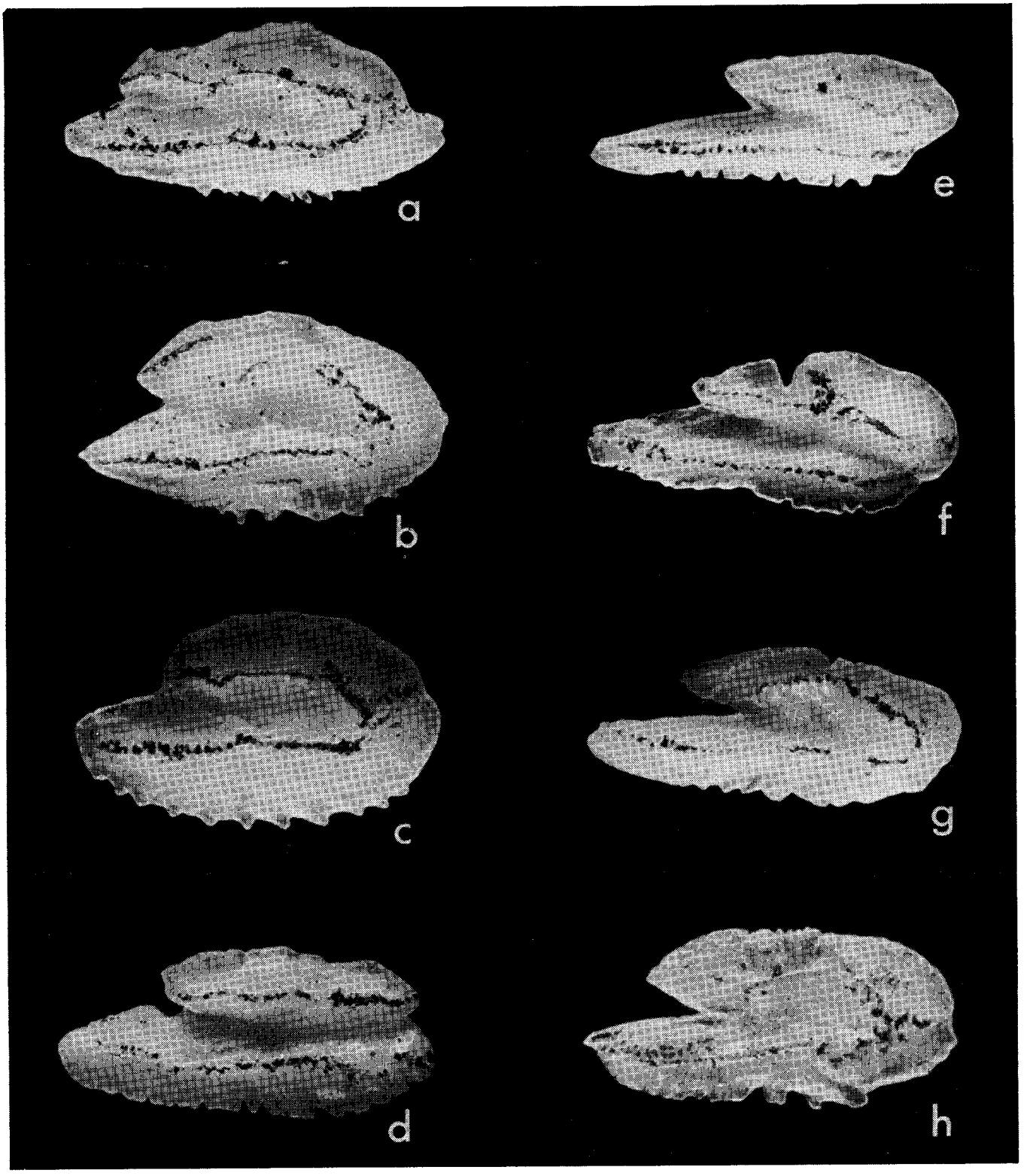

FIGURE 1. Right sagittae from adults of native genera of Californian engraulids and clupeids. The sulcus of each otolith has been highlighted by rubbing a pencil across the raised margins. Otolith lengths and heights (in mm) are given in parentheses. The eight species figured are: a. *Engraulis mordax* (4.5 x 2.1), b. *Centengraulis mysticetus* (4.2 x 2.4), c. *Anchoa compressa* (4.2 x 2.4), d. *Clupea pallasi* (4.6 x 2.0), e. *Sardinops caeruleus* (4.5 x 1.6), f. *Etrumeus teres* (4.4 x 1.9), g. *Opisthonema medirastre* (4.5 x 1.9), h. *Harengula thrissina* (2.5 x 1.2). *Photographs by Jack W. Schott.*

No *Scomber* otoliths have been recovered from Indian middens either, but Follett (1963a, 1963b, 1965) has identified vertebrae and dentary bones in three middens as having come from *S. japonicus,* and I have seen many Pacific mackerel vertebrae and jaw fragments in midden material I have examined. Possibly, *Scomber* otoliths require a more intricate combination of favorable conditions before fossilization can occur. If this is the case, and such conditions were not met during the Pleistocene, no amount of searching would turn up a Pacific mackerel otolith, even if dense schools had existed off our coast.

None of the fossil *Scomber* otoliths has been entire; only posterior ends have been recovered (Figure 3d).

Jack Mackerel

Although *Trachurus* sagittae resemble those of *Decapterus* in general outline and configuration, the two can be separated accurately by the degree of flexure of the cauda (Figure 2). Six of the seven coldwater

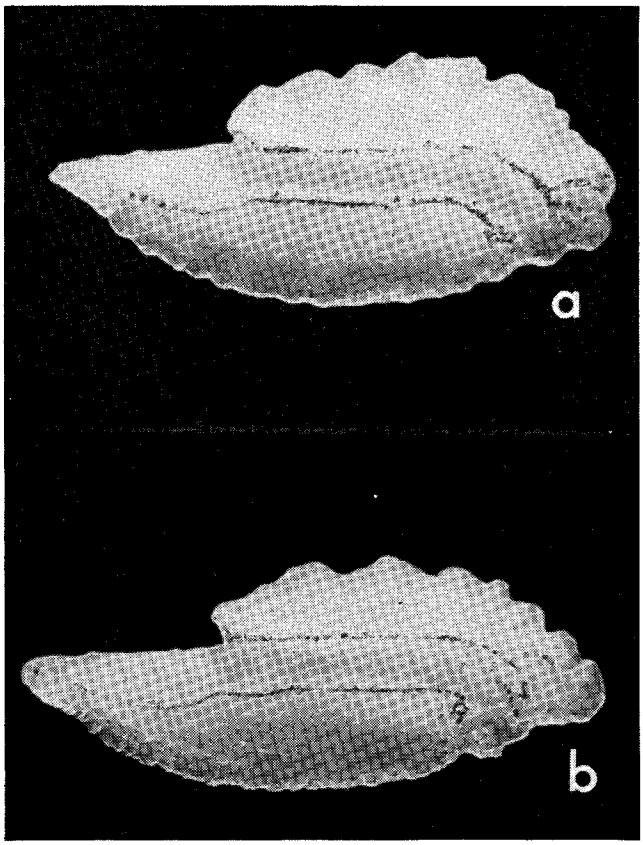

FIGURE 2. Right sagittae from similar sized *Trachurus symmetricus* (a), and *Decapterus hypodus* (b). Otolith lengths and heights (in mm) are: 6.0 x 2.5, and 7.5 x 3.0, respectively. The sulcus of each has been highlighted by rubbing a pencil across the raised margins. *Photographs by Jack W. Schott.*

deposits that I investigated (three of four Pleistocene and all three Pliocene) yielded *Trachurus* otoliths, but they were present in only one of the three warm-water sites (Playa del Rey, Table 1).

No jack mackerel otoliths were found in the four Indian middens reported upon here, but other *Trachurus* remains (e.g., posterior lateral line scutes) were noted, and a single sagitta has been found in a coastal midden at La Jolla.

Hake

Merluccius sagittae were not found in either of the San Pedro sand deposits that I investigated, and these were the only outcrops representing cold temperatures and shallow (possibly nearshore) depths at time of deposition (Table 1). Hake otoliths were present in all other Pleistocene deposits that yielded 500 or more otoliths (two shallow water warm deposits and two deep water cold localities), and were in all three Pliocene exposures, being very abundant in two of the three. Very few of the hake otoliths were from large fish, perhaps 90 percent representing fish-of-the-year.

Hake jaw fragments and vertebrae were plentiful in the Ven-3 Indian midden and were present at SBa-1, but no otoliths were found at any of the four sites investigated.

DISCUSSION

Indian middens and fossil deposits offer a nearly continuous record of the fish faunas that have existed off our shores during the most recent 125 million years of the earth's history. The species that were present between the Cretaceous and Miocene are mostly extinct, but many of these were the ancestors of present-day stocks. On the other hand, Pliocene and Pleistocene deposits in California have yielded otoliths from 144 species of teleosts, and all but one of these are living off our shores today.

Unfortunately, science has not progressed to the point that an exact date can be affixed to each fossil horizon regarding its time of deposition. There are few areas where geologists and paleontologists have not mastered the geochronology, but they have not been able to correlate with any degree of certainty a given bed in one locality with a given bed in another locality 500 or 1,000 miles away. When dating techniques have reached the stage of perfection that fossil deposits at Arcata can be matched with those at San Francisco, San Pedro, and San Diego, intricate details of paleoecology will be within reach of the inquisitive mind. Information on paleotemperatures, fish distributions, life history, predation, catastrophic events, etc. can be gleaned from fossil otoliths (Devereux, 1967; Fitch, 1964, 1967b) and used in conjunction with knowledge of today's happenings to help explain long- and short-term trends. Obviously, a complete history of *Sardinops* in time and space would permit speculation as to its future potential, and such questions as to whether it has been displaced by the anchovy, whether it was ever very important except during the 1930's etc., would no longer be academic.

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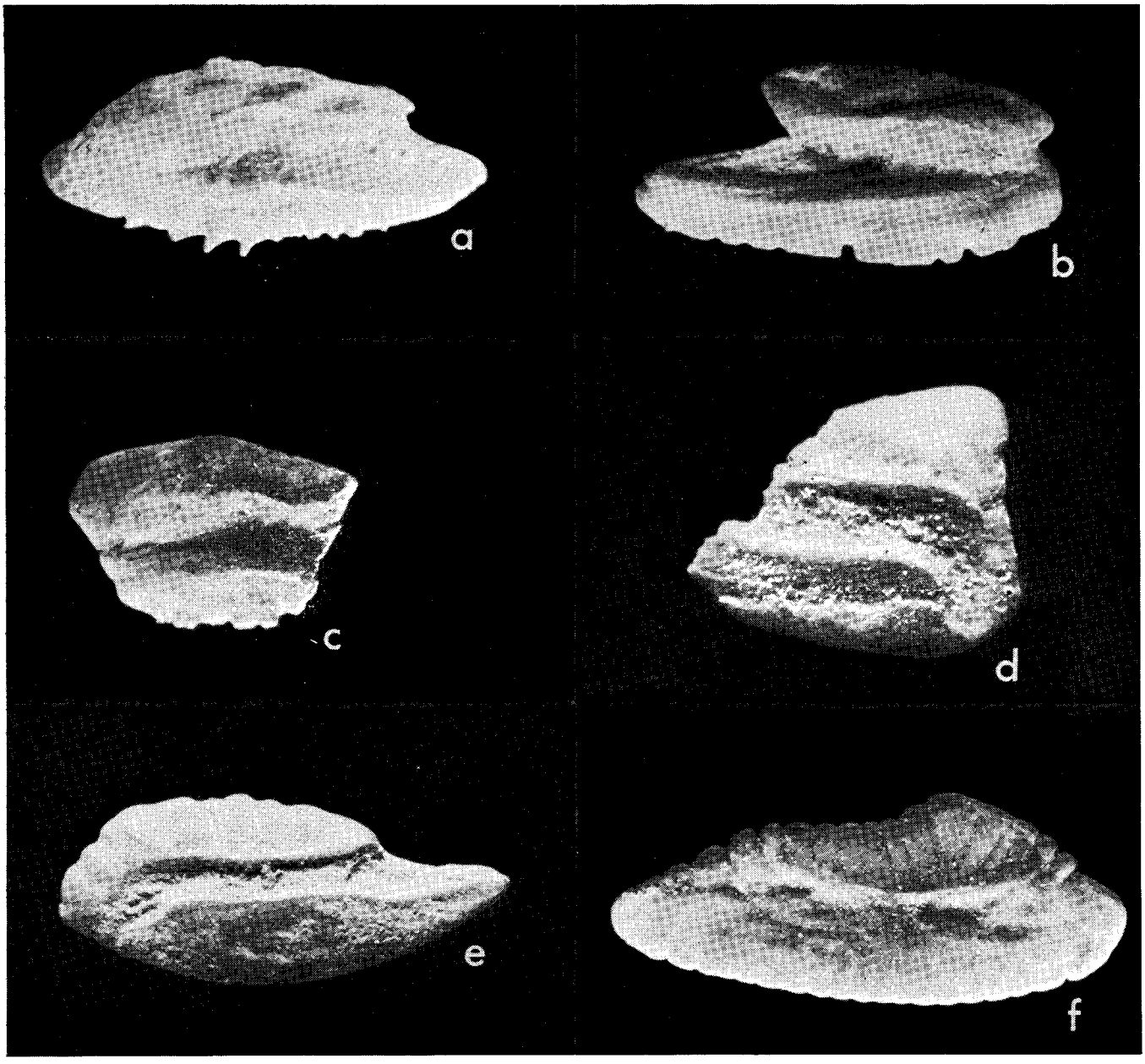

FIGURE 3. Sagittae of certain schooling fishes recovered from an Indian midden and various southern California Pleistocene and Pliocene deposits. Only posterior portions of *Sardinops* and *Scomber* otoliths have been recovered, but otoliths of the other four species are often entire. Lengths are given for each figured otolith or fragment, and notation is made as to whether it is a left or right sagitta. The six species are: a. *Engraulis mordax*, 3.9 mm, l., Ventura Freeway, early Pleistocene; b. *Clupea pallasi*, 3.7 mm, r., Miraleste Canyon, Pliocene; c. *Sardinops caeruleus*, 2.0 mm, l., SBa-1 Indian midden; d. *Scomber japonicus*, 1.7 mm, r., Newport Mesa, Pliocene; e. *Trachurus symmetricus*, 4.8 mm, l., Newport Mesa, Pliocene; f. *Merluccius productus*, 6.2 mm., l., Newport Mesa, Pliocene. *Photographs by Jack W. Schott.*

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