# III

# Use of Fossil Fish Scales in Micropaleontology

Lore Rose David

With six plates and nine text figures

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CONTRIBUTIONS TO PALEONTOLOGY

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## Introduction

Fossil fish remains are abundantly represented in the marine sedimentary rocks of California. Certain shaly formations are littered with dismembered parts of fish, for example scales and single bones, though few other fossils are found in them. Up to the present time, these fossils have not been utilized in geological and paleontological work in California. An attempt has been made by the author to collect a variety of distinguishable fossils of this kind and to determine to what degree these scale assemblages differ in different stratigraphic units. Approximately 75 distinct types of scale have been found, and the more important ones are illustrated in this paper.

The present report is preliminary in many respects. Only a small number of genera are definitely determined. No names are given to the new forms at present. Instead, the genera are designated by number, the species by letter. It is hoped that the illustrations and identifications will nevertheless be of use to paleontologists.

A general outline for work on fish scales and a description of the technique employed in the study of this kind of material was given by Camp and Hanna (*Methods in Paleontology,* 1937, p. 127). The methods described by these authors can be readily adapted to individual needs.

The investigation on fossil fish scales here reported, conducted during 1941–1942, was supported by several petroleum companies, and it is a pleasure to acknowledge the generosity of these concerns. I wish to thank Dr. Chester Stock for his active interest in the various aspects of the research and for the facilities offered in the paleontological laboratory of the California Institute of Technology. To M. L. Natland, of the Richfield Oil Corporation, I am indebted for the excellent enlarged photographs of fossil scales which he so kindly made and contributed.

## Description of Material

*Occurrence and composition of assemblages.* Fossil fish faunas represented by complete skeletons have been found at a number of localities in California, but are restricted almost entirely to the Upper Miocene. Some of these fish faunas are of considerable diversity and give definite information as to conditions of accumulation of the sediments at the place of their occurrence (see David, Geol. Soc. Amer. Spec. Pub. 43, 1943). Scales and dismembered remains of fish are scattered at intervals throughout the entire Tertiary stratigraphic section and are also found in the Upper Cretaceous. Fish remains are present to some degree nearly everywhere, but are often too fragmentary and distorted to be determinable. At intervals richer zones, comparable to the flood zones of the foraminifera, are found, showing a better preservation and a greater variety of forms. Such zones are easily recognized in the field, especially in well cores.

A fish-scale assemblage found fossil cannot be compared with a normal living fish fauna of a given locality. Generally the former shows an abundance of individuals but small variety, and represents a joint occurrence rather than a faunal assemblage of more heterogeneous elements. Fishes that occur abundantly and in large schools in the oceanic realms are likely to leave more frequent records than the rarer forms. It will be seen that certain types are by far the most common in certain sections. Often these types are found to the exclusion of all others, the specific forms changing with the progress of time. These dominant types, because of their more general occurrence, are the most useful for correlation purposes.

Scales of herring-like fishes (Clupeoidea) are extremely abundant in sedimentary accumulations laid down in shallow water, or in the neritic zone and

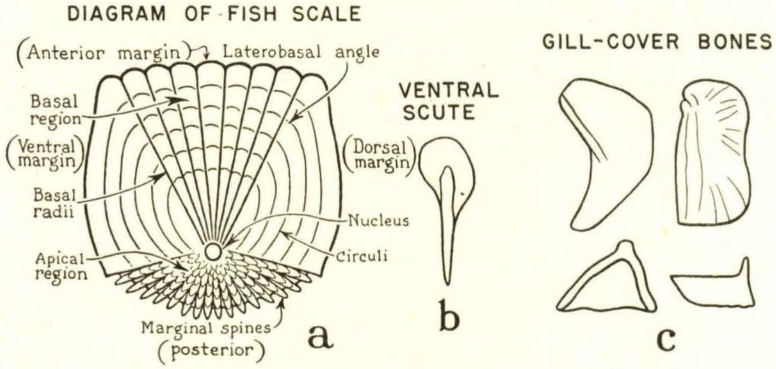



FIG. 1. Diagrams of fish remains most commonly found

extending into bathyal regions. Silversides (Atherinidae), mackerels (Scombridae), jacks (Carangidae), and, to a certain degree, pipefishes (*Syngnathus*) are also more commonly found in coastal deposits. In regions of deep water, the place of the herrings is taken by a family restricted to abyssal depth, the rattails (Macrouridae). Scales of these fishes are among the best preserved in the California Tertiary.

Text figure 1*a* illustrates diagrammatically a typical teleostean fish scale, showing the different parts of its sculpture: The basal covered region, where the scale is attached, is most often characterized by strongly folded basal radii; the apical uncovered part of the scale may be with or without marginal spines; the premarginal part of the apical pole may be characterized by radii, a radial network, tubercles, or patterns of differently shaped premarginal teeth. The greater part of the scale is generally sculptured by the circuli, fine lines, most often circular, which take different directions toward the margin of the scale, and are sometimes characterized by a strong laterobasal angle. The center of the circuli is called the nucleus or focus; the apical part of the scale may be free from circuli. Clupeoid scales are marked by strong transverse radii, which are not found so well developed in any other group of fishes.

The scale characters readily permit one to distinguish families and genera. Specific differences can also be determined to a certain extent. The occurrence of fossil types in certain strata, their appearance at intervals interrupted by a lapse of time, favors differentiation into subdivisions of genera and species.

Various single bones of fish are found in the stratigraphic section. Most often these are gill-cover bones. Text figure 1*c* shows the opercular bones of *Etringus,* a round herring, as found in the lower Saucesian; figure 1*b* shows a part of the ventral skeleton of the same form. Various fish jaws are likewise found. Plate 1, figure 2 shows the jaws of a long-toothed abyssal form; figures 1 and 1*a* show head and opercular bones of a pipefish. Fish teeth and ear bones are found in washed samples of foraminifera from certain zones.

## Several Typical Scale Assemblages from the California Tertiary

Well cores and surface sections of different formations and of various ages have been studied for fish remains. All locations of oil wells given, unless otherwise indicated, are Mount Diablo base line and meridian.

### *Eocene $A_1$, Eocene $A_2$,—Kreyenhagen Formation*

Fish scales are very common in the Kreyenhagen. Only the three most abundant types are figured (pl. 1, figs. 3–5), all from the Seaboard Oil Company Well, Welch No. 1, Sec. 10, T. 16 S., R. 13 E. Two clupeoid forms are most commonly represented in the upper layers of the formation. In the list which follows, the numbers refer to the figures on plate 1.

No. 3. Suborder Clupeoidea. From depth of 4037± feet. Scale 4 mm. long, 5 mm. deep.

No. 4. Family Clupeidae. From depth of 4236 feet. Scale 5.25 mm. long, 6.5 mm. deep.

No. 5. Order Berycomorphi, family Polymixiidae. From depth of 4279± feet. Scale 2.88 mm. long, 2.35 mm. deep. This bathyal genus is extremely abundant in the lower Kreyenhagen, whence the material comes, and is found repeatedly in the section. Basal part of scale very irregularly folded; angular circuli fine and widely spaced, disappearing toward the apical region; marginal spines along apical margin, longest in center.

The same form is found in the Amerada Petroleum Company Well, Beer No. 1, Sec. 17, T. 26 S., R. 19 E., at depth of 4026 feet and still deeper (Eocene $A_1$). It also occurs in cores of the Texas Company Pioneer Unit Plan Well No. 1, Sec. 33, T. 11 S., R. 23 E., at depth of 8085 feet and still deeper (Eocene $A_2$).

### *Refugian*

The Refugian stage has been studied from cores of the Amerada Petroleum Company Well, Beer No. 1, Sec. 17, T. 26 S., R. 19 E., west of the Williamson area. The well core is comparatively sandy, however, and the samples available are few. The more characteristic types of a deep bathyal assemblage from the 3500-foot level in this well are shown in plate 1, figures 6–10. They are listed as follows:

No. 6. Family Chaetodontidae?: undescribed genus. From depth of 3540 feet. Elongate acanthopterygian scale, 6.5 mm. long, 4 mm. deep. This type of scale probably ranges higher in the Lower Miocene.

No. 7. Family Halosauridae: undescribed genus. From depth of 3494 feet. Scale 5 mm. long, 3.5 mm. deep.

No. 8. Order Iniomi. From depth of 3513 feet. Scale 1.94 mm. long, 2.59 mm. deep.

No. 9. Family ?. From depth of 3500 feet. Scale 3.25 mm. long, 4 mm. deep. This type of ovoid scale probably ranges downward from the Refugian into the Eocene. Circuli extend entirely around scale; nucleus almost in center of scale; irregular radial radii range all around scale margin.

No. 10. Family Macrouridae: undescribed genus. From depth of 3540 feet. Scale 1 mm. long, 1.5 mm. deep. Spinous apical region makes up greater part of scale.

### *Zemorrian*

A very satisfactory Zemorrian section is found in cores of the Texas Company Pioneer Unit Plan Well No. 1, Sec. 33, T. 11 N., R. 23 W., San Bernardino base line and meridian, in the southern Sunset district, San Joaquin Valley, California.

*Upper Zemorrian.* Range of *Siphogenerina mayi:* The Upper Zemorrian here shows a deep neritic assemblage, largely dominated by a species of the clupeoid genus *Etringus,* a round herring (pl. 2, figs. 11, 11*a*; text fig. 2). An assemblage not unlike this was found in the Ohio Oil Company "K.C.L.-G." Well No. 1, Sec. 36, T. 29 S., R. 26 E., Fruitvale district, coming near the horizon of a *Siphogenerina* flood zone (*S. transversa, S. mayi,* and *Uvigerinella obesa* are present). The following types are listed, the numbers referring to the figures on plate 2.

No. 11. Family Dussumieridae: *Etringus* sp. "K.C.L.-G." Well No. 1, at depth of 10,434± feet. Scale 5.5 mm. long, 6.5 mm. deep.

No. 11*a*. Family Dussumieridae: *Etringus,* same species. P.U.P. Well No. 1, at depth of 4352 feet. Scale 6 mm. long, 7 mm. deep. This scale is of an older fish than that shown in figure 11, and is slightly distorted; the apical pole is compacted in depth. The scales shown in text figure 2 are from three different wells. The elongate type of scale with the greater number of transverse radii is much rarer than the ovoid type. The number of transverse and apical radii increases with age and size of scale.

Pipefish are not rare in the assemblage (pl. 1, figs. 1, 1*a*) from the P.U.P. well, and are very abundant in well cores from the Fruitvale district:

No. 1. Family Syngnathidae: head of *Syngnathus.* "K.C.L.-G." Well No. 1, at depth of 10,450± feet. 14.5 mm. long, 7 mm. deep.

No. 1*a*. Family Syngnathidae: opercular of *Syngnathus.* P.U.P. Well No. 1, at depth of 4214 feet. 4.5 mm. long, 3.5 mm. deep.

Three species of jack are present in the assemblage, two of which are figured here:

No. 12. Family Carangidae: *Seriola* sp., yellowtail. "K.C.L.-G." Well No. 1, at depth of 10,434 feet. Scale 1.5 mm. long, 0.6 mm. deep.

No. 13. Family Carangidae: *Seriola* sp., yellowtail. "K.C.L.-G." Well No. 1, at depth of 10,434 feet. Diameter of scale 2.5 mm.

A comparatively large scale of a silverside is present:

No. 14. Family Atherinidae. "K.C.L.-G." Well No. 1, at depth of 10,450 feet. Scale 4 mm. long, 4 mm. deep.

No. 14*a*. Family Atherinidae. P.U.P. Well No. 1, at depth of 4344 feet. Scale 3.25 mm. long, 5 mm. deep.

The scales shown in figures 14 and 14*a* evidently belong to the same species.

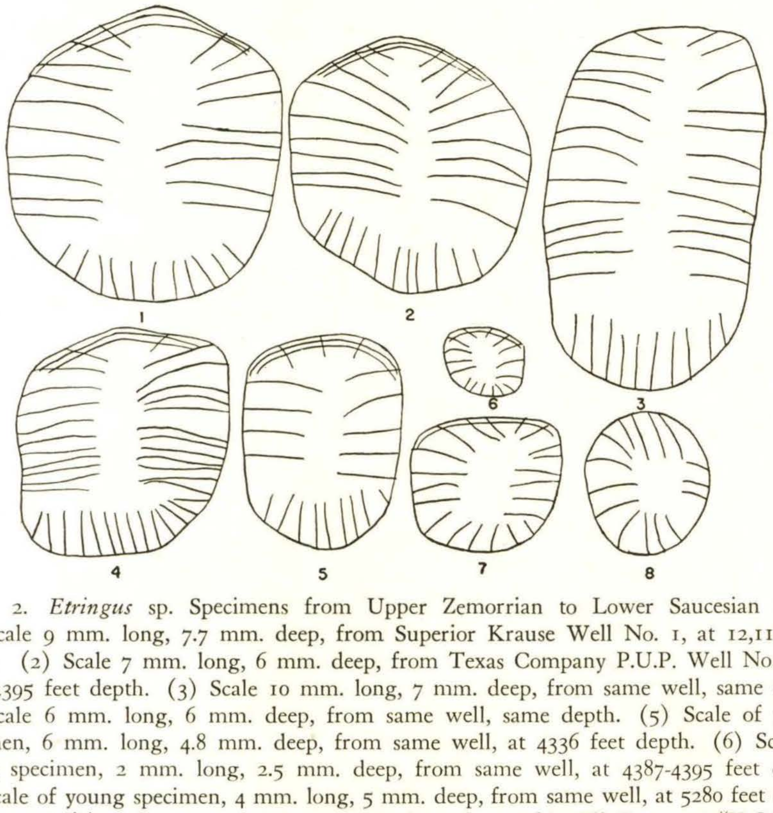



FIG. 2. *Etringus* sp. Specimens from Upper Zemorrian to Lower Saucesian strata. (1) Scale 9 mm. long, 7.7 mm. deep, from Superior Krause Well No. 1, at 12,118 feet depth. (2) Scale 7 mm. long, 6 mm. deep, from Texas Company P.U.P. Well No. 1, at 4387–4395 feet depth. (3) Scale 10 mm. long, 7 mm. deep, from same well, same depth. (4) Scale 6 mm. long, 6 mm. deep, from same well, same depth. (5) Scale of young specimen, 6 mm. long, 4.8 mm. deep, from same well, at 4336 feet depth. (6) Scale of young specimen, 2 mm. long, 2.5 mm. deep, from same well, at 4387-4395 feet depth. (7) Scale of young specimen, 4 mm. long, 5 mm. deep, from same well, at 5280 feet depth. (8) Ventral (?) scale 5 mm. long, 3.75 mm. deep, from Ohio Oil Company "K.C.L.-G." Well No. 1, at 10,430 feet depth.

No. 15. Suborder Salmonoidea. This form seems typical of the Californian stratigraphic section from the Lower Saucesian downward. No related salmon occurs in the California sea today. Scale 15 (pl. 2) comes from the Superior Krause Well No. 1, Fruitvale district, Sec. 2, T. 29 S., R. 26 E., probably from a slightly older horizon (*Siphogenerina nodifera* ?), at depth of 12,118 feet. It was found in a small sample, where the species of *Etringus* was dominant. Scale 5.88 mm. long, 3.94 mm. deep.

Bones from the opercular region of *Etringus* and also a ventral scute (text fig. 1*b, c*) are frequent in the Upper Zemorrian encountered in the P.U.P. well. A greater number of these bones are found in the Fruitvale zone.

*Middle Zemorrian.* This division comprises the lower part of the range of *Siphogenerina nodifera* and *Uvigenerina belridgensis.* Beginning with the upper Middle Zemorrian, rattails appear in the stratigraphic sequence of the P.U.P. well, indicating presence of a deeper sea. A small form with feeble radii and hardly any spines (pl. 2, fig. 16) appears latest in the section, and is found in the uppermost Middle Zemorrian. In the middle of the Upper Zemorrian, coincidentally with the first appearance of *Uvigenerina belridgensis,* rattails become more abundant, and in the lower Middle Zemorrian rattails are dominant in the section. In large parts of the section nothing but rattails (pl. 2, figs. 16–20) is found; in these zones the sea evidently was more than 1000 fathoms deep. These horizons are interrupted by regions where *Etringus* again becomes somewhat more frequent, but this form is always badly preserved at this depth. The dark shale containing an abundance of rattail is also interrupted several times by a highly sandy shale.

All rattails (Macrouridae) shown (pl. 2) come from the P.U.P. Well No. 1:

No. 16. Family Macrouridae. From depth of 4517± feet. Scale 3 mm. long, 2.5 mm. deep.

No. 17. Family Macrouridae. From depth of 5460 feet. Scale 5.25 mm. long, 4 mm. deep.

No. 18. Family Macrouridae. From depth of 6558 feet. Positive, sculptured side of scale, 4 mm. long, 4.24 mm. deep.

No. 18*a*. Family Macrouridae. From depth of 6228 feet. Mold of sculptured side of scale, 3.12 mm. long, 4.06 mm. deep.

No. 19. Family Macrouridae. From depth of 5688 feet. Mold of sculptured side of scale, 2.94 mm. long, 3.76 mm. deep.

No. 20. Family Macrouridae. From depth of 6558 feet. Smooth side of scale, 2.82 mm. long, 3.12 mm. deep.

*Lower Zemorrian.* This zone is characterized by the foraminifer *Anomalina californiensis.* The fish assemblage present in the lower Zemorrian of the P.U.P. well is different from that found higher in the section. Rattails disappear almost entirely; nearly all the genera present, however, are bathyal types. The large scale no. 24 (pl. 3) is rather frequent and most typical of the section. This appears to be the upper limit of its occurrence. Herring scales are present, but nearly always distorted, and it seems likely but not certain that a species change has taken place. All scales listed below are from the P.U.P. Well No. 1:

No. 21. Family Thunnidae: possibly *Thunnus.* From depth of 7600 feet. Scale 3.23 mm. long, 3.6 mm. deep.

No. 22. Order Iniomi: undescribed genus. From depth of 6622 feet. Scale 4 mm. long, 4.5 mm. deep.

No. 23. Family Halosauridae: *Laytonia* sp. From depth of 7304 feet. Scale 3.82 mm. long, 3.52 mm. deep. A scale nearly related to this one was described by T. D. A. Cockerell (U. S. Geol. Surv. Prof. Paper 120, p. 184, 1919).

No. 24. Order Berycomorphi, family ?. From depth of 7400 feet. Scale 7.5 mm. long, 7.7 mm. deep.

These Zemorrian assemblages are highly interesting, even though they come almost entirely from one well. The stratigraphic section shows very distinctly a subdivision into three parts. The distinctness of the lowermost assemblage indicates that a general faunal change occurred between that period and those that follow, causing extinction of certain types. The change occurring between the upper and middle parts of the section is explained entirely by facies differences.

### *Saucesian*

The lower Saucesian is marked in thick sections by a great abundance of opercular bones belonging to *Etringus*. This fact has already been reported for the Lower Saucesian to Upper Zemorrian in the Ohio Oil Company "K.C.L.-G." Well No. 1, and is found to hold also for the cores of the P.U.P. well sampling strata overlying the Upper Zemorrian. The same fact can be recorded for the Saucesian of the Associated Williamson Well No. 1, Sec. 2, T. 26 S., R. 20 E., Williamson area, at a depth of approximately 6600 feet and lower. Several small samples from the Etienne Lang "Occidental" Well No. 2, Sec. 30, T. 26 S., R. 19 E., west of the Lost Hills area, from the Santos shale showed the same forms, as well as samples from the Harold C. Morton Well No. 1 analogue Etienne Lang "Occidental" No. 2, in the same region. These bones occur frequently again in the Saucesian of the Texas Company Well, Newman No. 1, Sec. 23, T. 29 S., R. 28 E., on the southeastern border of the San Joaquin Valley, at a depth of approximately 5800 feet and lower. The accompanying scales of *Etringus* found in these sections are small compared with those found in the Upper Zemorrian, a difference which may be explained by local conditions. A great many fragments of fish bones were observed in washed samples from the Saucesian and Upper Zemorrian of Los Sauces Creek. One or two different clupeoid forms evidently occur in the Upper Saucesian, but sufficient material has not been seen. A more continuous Saucesian section has been studied in the Texas Company Well, Newman No. 1 (pl. 3), Kern River district, Sec. 23, T. 29 S., R. 28 E. Not much material is available, however, and the well is quite sandy. A number of coastal shallow-water forms of fish are present in the Upper Saucesian, mostly too fragmentary for exact determination.

No. 25. Family Clupeidae: a clupeid form, probably a young shad. From depth of 3748 feet. Length of scale 4.71 mm., depth 5.76 mm.

Macrouridae are present in the lower part of the well, but are not dominant. A small scale of a rattail is present in higher horizons:

No. 26. Family Macrouridae. From depth of 5423 feet. Length of scale 2.41 mm., depth 2.65 mm.

No. 27. Family Macrouridae: a quite different species of rattail. From depth of 5741 feet. Length of scale 2.94 mm. with spines, depth 2.94 mm.

Other species of rattail appear farther down in the well. Finally there appears also occasionally no. 18, shown for the Zemorrian.

### *Relizian and Luisian*

Both stages are represented in the Newman Well No. 1, but the material is not very satisfactory. The clupeid form no. 25 is present in both stages.

A typical round herring is characteristic of the Relizian:

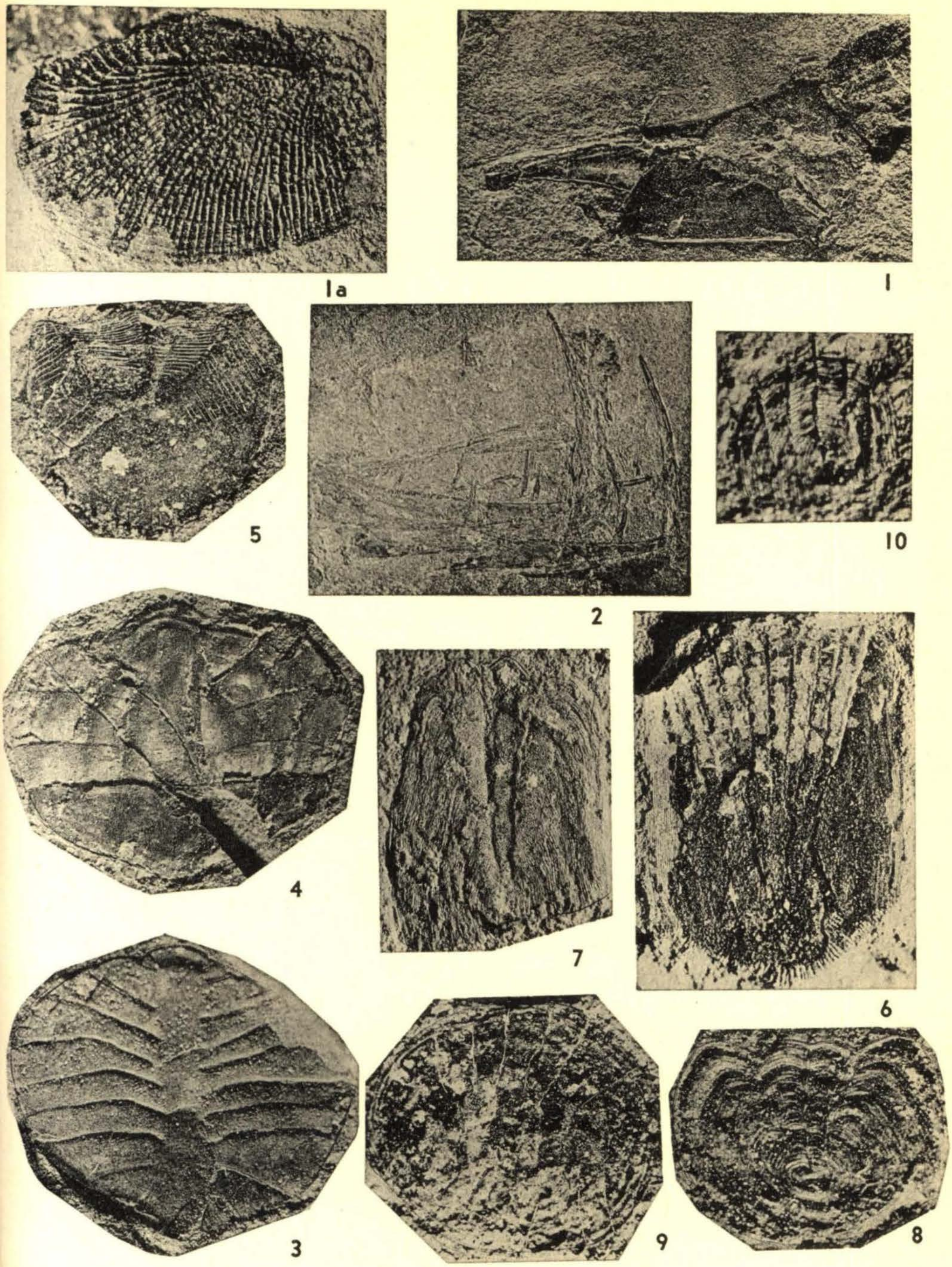
No. 28. Family Dussumieridae. From depth of 3639 feet. Length of scale 4 mm., depth 5.29 mm.

The assemblage is near-shore neritic, the more common types beings jacks and smelts, with a few acanthopterygians also present. The Luisian seems to be characterized by porgy fishes, for example *Rhythmias* and *Plectrites* (not figured).

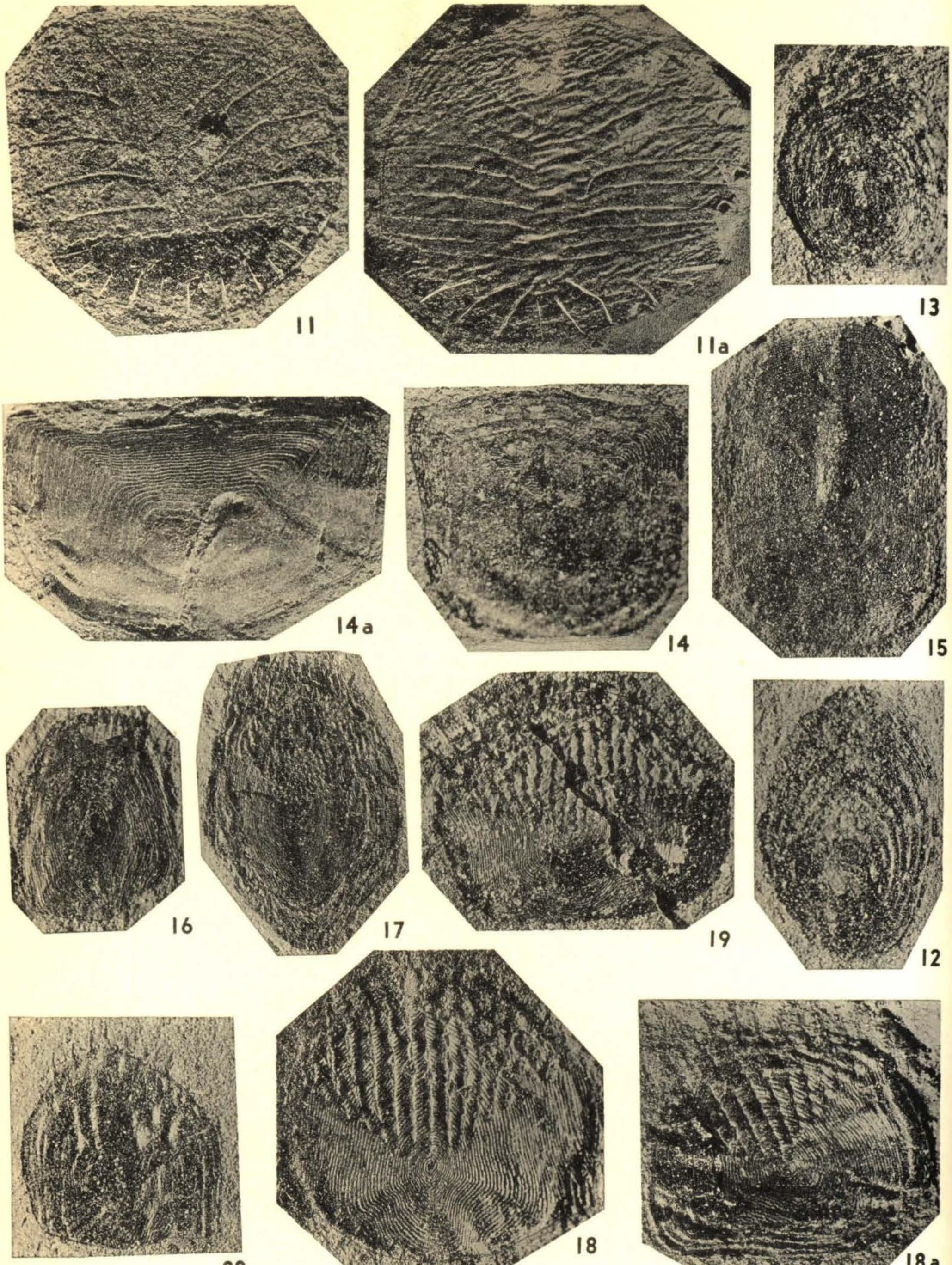
### *Mohnian*

The greatest variety of scales is found in the Mohnian. This is also the stage from which come the majority of the more completely assembled fish skeletons. The Mohnian assemblages are in general neritic, with types indicating local deepening of the sea. The Mohnian has been studied from outcrops in the Santa Monica Mountains. Localities in the eastern part of the mountains are for the most part near Sepulveda Canyon (for descriptions of localities see David, Geol. Soc. Amer. Spec. Pub. 43, 1943). Fossil sites in the type region of the Mohnian (Girard-Mohnsprings, now called Girard–Mineral Springs) are the same as Hoots' foraminiferal localities (U. S. Geol. Surv. Prof. Paper 165C, 1931). Our knowledge of these sections is still incomplete, and more collecting, with detailed stratigraphic studies, is desirable. Several small samples from the Western Gulf Oil Company Symons Well No. 12-17, Sec. 7, T. 32 S., R. 27 E., Buena Vista district, San Joaquin Valley, furnished Upper Mohnian material from below the Stevens zone. The Western Gulf Oil Company Lechler Well No. 1 from Oakridge also furnished some scattered Upper Mohnian scales. Lower Mohnian was found in the Findley Frazier "Portals" Well No. 1, Sec. 4, T. 30 S., R. 29 E., Edison district.

*Mohnian clupeoid fishes.* Some remarks regarding the occurrence and use of this type of scale seem desirable here. Scales of herring-like fishes are well differentiated from those of all other groups. They are characterized by well marked, variously directed transverse radii on the basal part, generally paired, the lowermost pair united more often to form a complete ridge separating the apical part from the remaining part of the scale. The circuli are always very fine and cover the basal part; to the left and right of the center they extend onto the apical part, where they widen somewhat; they are slightly curved in the dorsoventral direction. The apical part is of simplified structure, divided only by apical radii differing in number. Scales differ more strikingly on the same fish in the herrings than in some of the other groups (Storey, Stanford Ichthyol. Bull., vol. 11, pp. 21, 22, 1938). However, the majority of scales from




Upper Eocene and Lower Miocene Fish Remains




LOWER MIOCENE FISH SCALES

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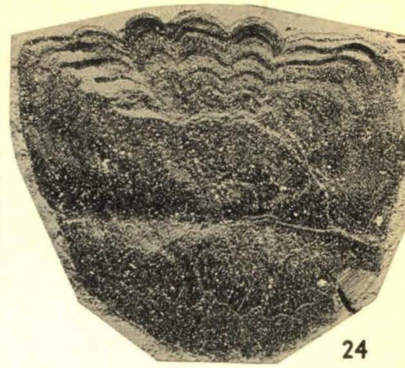

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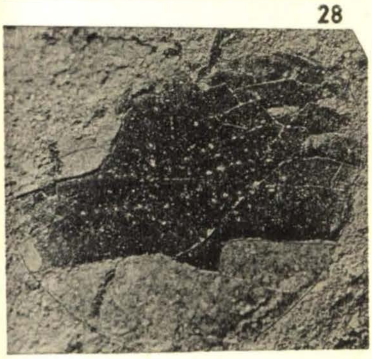

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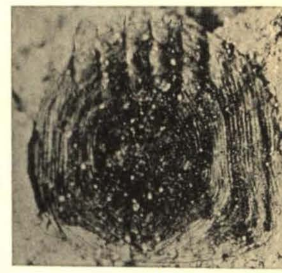

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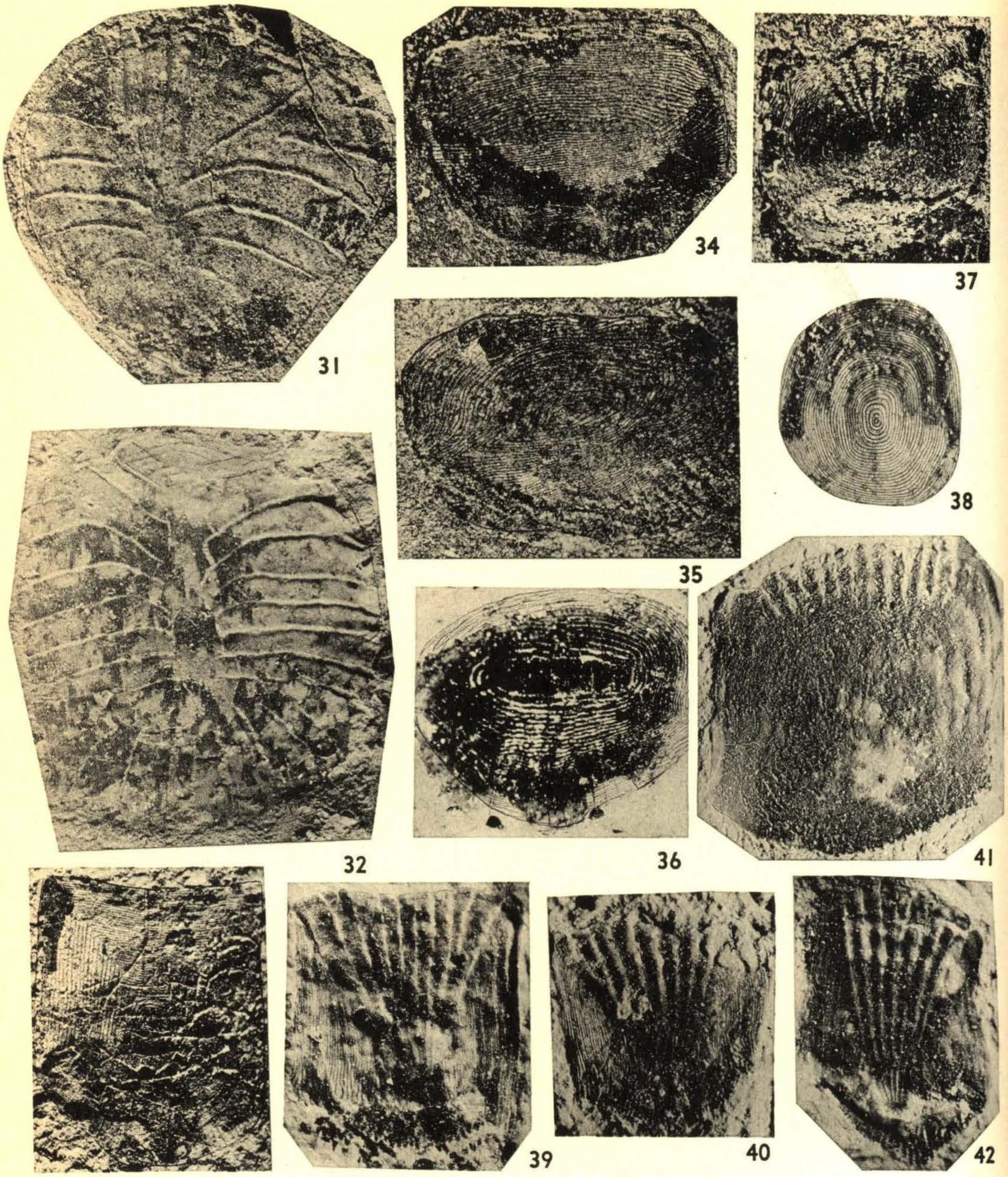
MIDDLE, LOWER, AND UPPER MIOCENE FISH SCALES




UPPER MIOCENE FISH SCALES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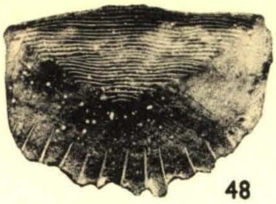
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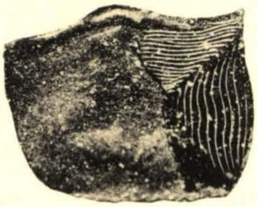
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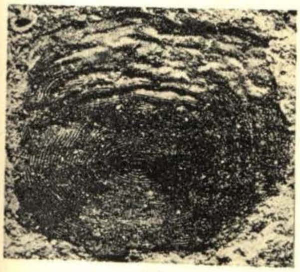
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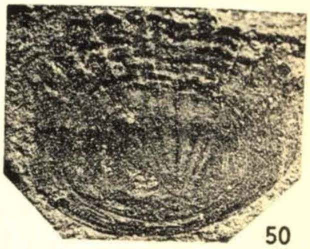
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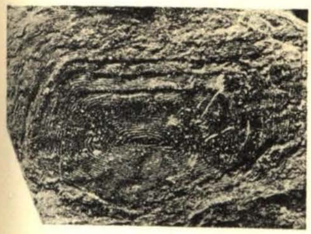
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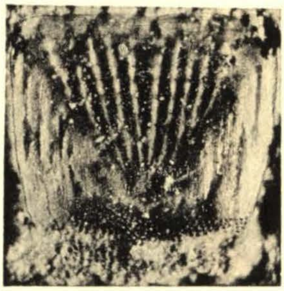
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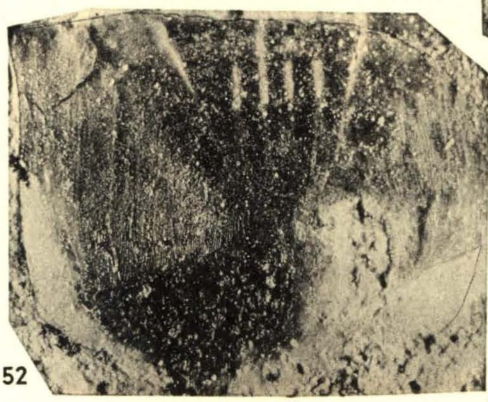
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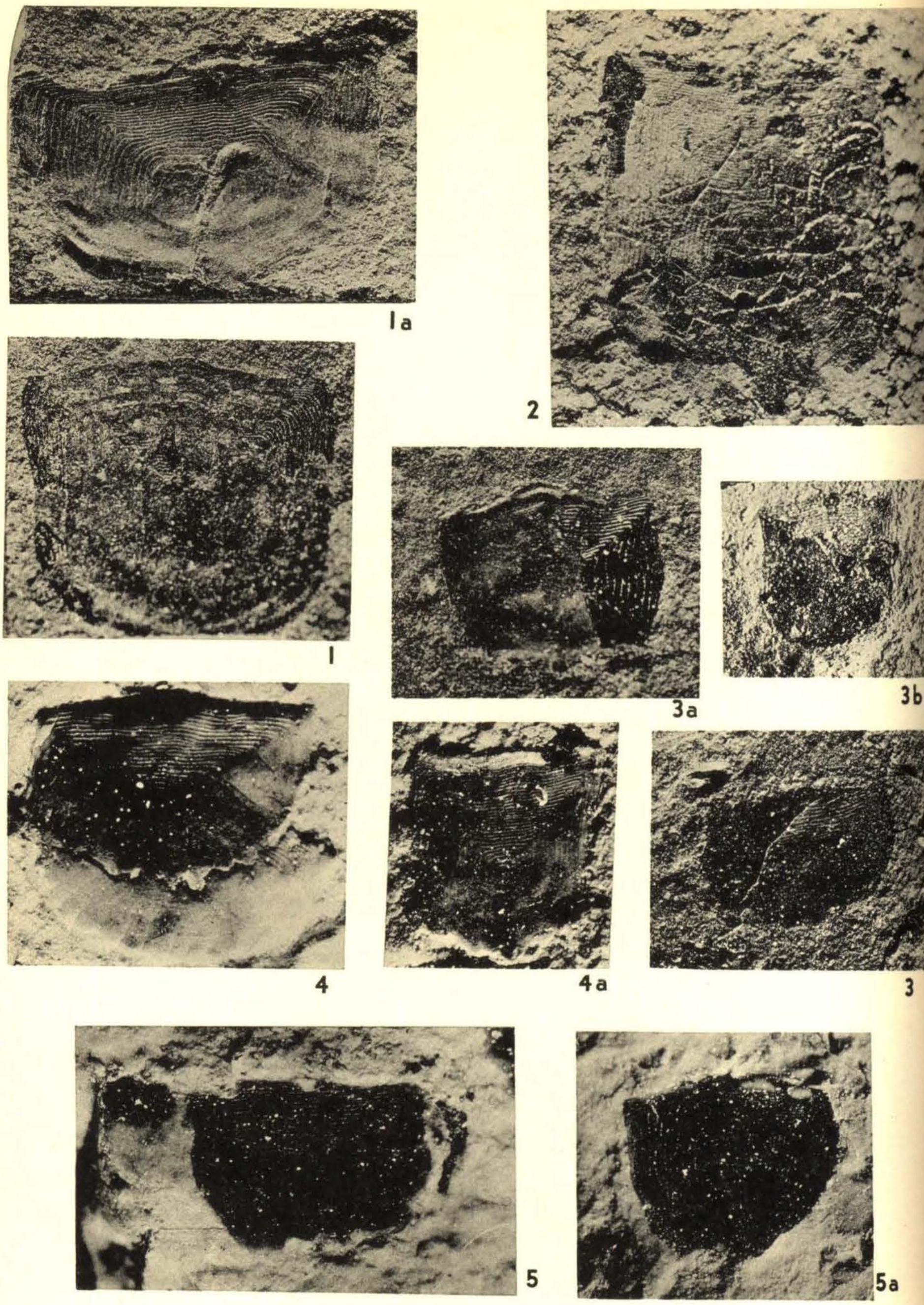
UPPER MIOCENE FISH SCALES




TERTIARY SILVERSIDES FROM CALIFORNIA

each fish, that is all the lateral scales, are similar. Scales toward the dorsal and ventral extremities of the body are aberrant. The aberrant scales may show transitions between different types and are often hard to distinguish. It is therefore advisable not to attempt determination on the basis of a single scale, but to consider a number of scales showing the variety present in a given horizon. As has been stated, herrings are always present in greater abundance than other fishes.

Four genera of herring-like fishes (see text figs. 3–6) are found in different parts of the Mohnian section. Typical specimens of the different forms are shown on plate 3, figures 29, 30, and plate 4, figures 31, 32. The drawings (text figs. 3–6) show the variations in scales of each type.

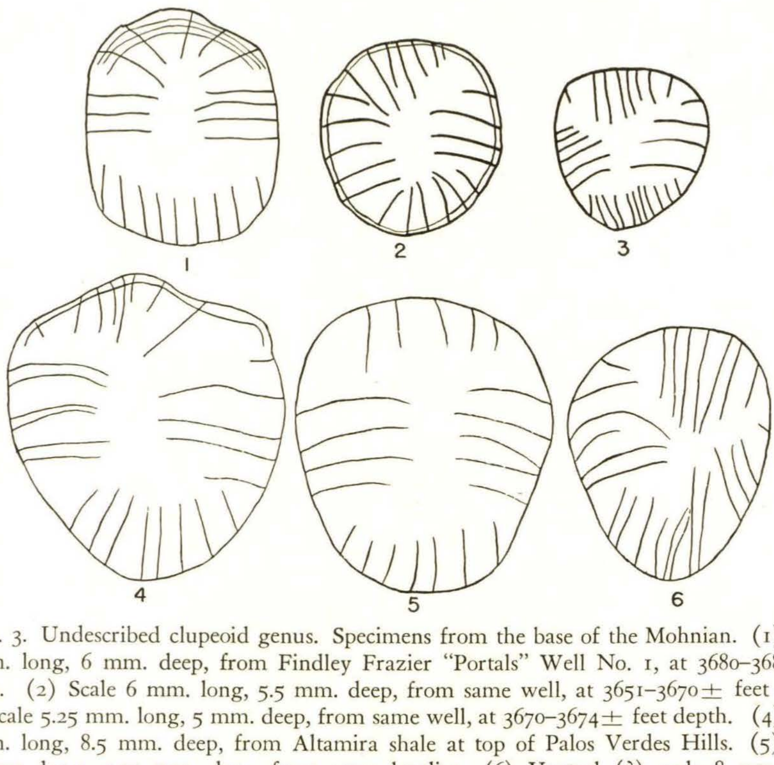



FIG. 3. Undescribed clupeoid genus. Specimens from the base of the Mohnian. (1) Scale 7 mm. long, 6 mm. deep, from Findley Frazier "Portals" Well No. 1, at 3680–3685 feet depth. (2) Scale 6 mm. long, 5.5 mm. deep, from same well, at 3651–3670± feet depth. (3) Scale 5.25 mm. long, 5 mm. deep, from same well, at 3670–3674± feet depth. (4) Scale 9 mm. long, 8.5 mm. deep, from Altamira shale at top of Palos Verdes Hills. (5) Scale 6.2 mm. long, 5.25 mm. deep, from same locality. (6) Ventral (?) scale 8 mm. long, 6.25 mm. deep, from Findley Frazier "Portals" Well No. 1, at 3680–3685± feet depth.

No. 31. Family Dussumieridae: ?*Etringus* sp., from the base of the Mohnian (text fig. 3). The scale occurs in the Altamira shale of the Palos Verdes Hills. The same scale has been found in the Findley Frazier "Portals" Well No. 1, in the *Pulvinulinella gyroidinaformis* zone, probably in the lower third of this zone. The form is characterized by transverse radii running in various directions; the number of parallel paired transverse radii, if present, is smaller than in the following form. This specimen comes from Findley Frazier "Portals" Well No. 1, at depth of 3660 feet. Length 5.5 mm., depth 5.47 mm.

No. 32. Family Dussumieridae: *Etringus scintillans* (text fig. 4), a round herring extremely abundant in the Lower Modelo of the Santa Monica Mountains. It was found in the Sepulveda Canyon region at localities corresponding to Hoots' unit 7 or 7 to 8, extending to and including the lower half of 9 (*Bolivina hughsi* zone) of

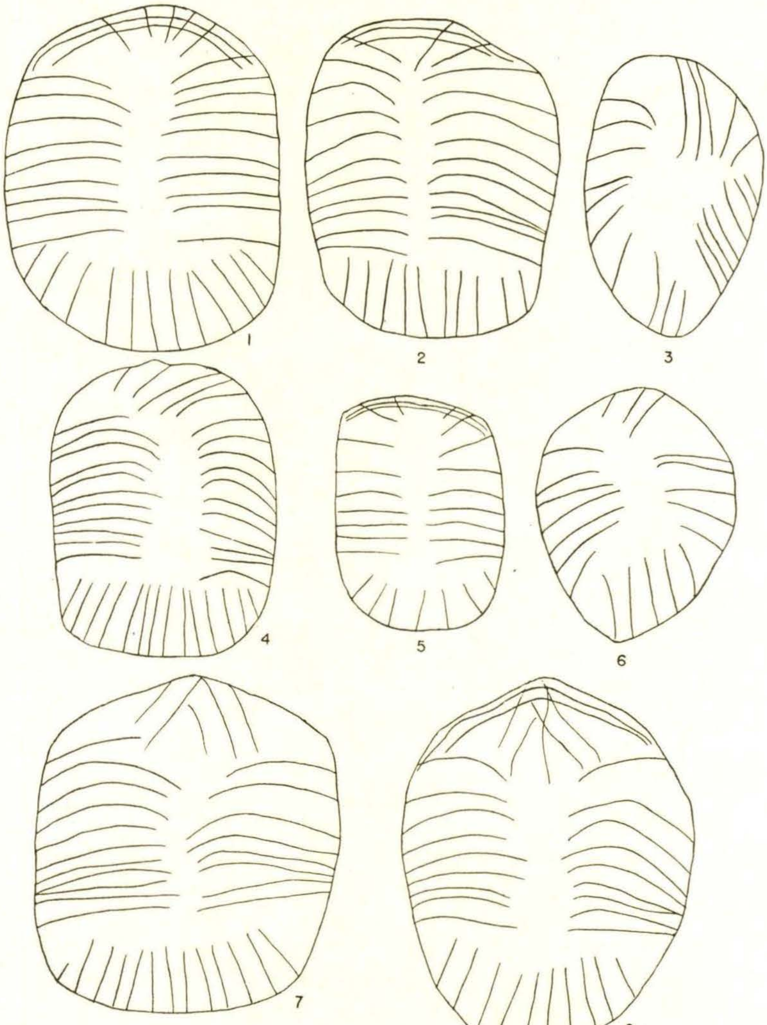



FIG. 4. *Etringus scintillans*. Specimens from Lower to Middle Mohnian strata. (1) Scale 11.75 mm. long, 9 mm. deep, from Sepulveda Canyon, Santa Monica Mountains, C.I.T. locality 334. (2) Scale 11 mm. long, 8 mm. deep, from Axis Company Rowland Well No. 1, at 2105–2127 feet depth. (3) Ventral (?) scale 9.5 mm. long, 5.5 mm. deep, from same locality as (1). (4) Scale 13 mm. long, 10 mm. deep, from Girard–Mineral Springs, Santa Monica Mountains, near Hoots' locality 117. (5) Scale of young specimen, 7 mm. long, 6.2 mm. deep, from same locality as (1). (6) Dorsal (?) scale 8 mm. long, 6 mm. deep, from same locality. (7) Scale 10 mm. long, 10 mm. deep, from Kraemer shale, Puente Hills. (8) Scale 11 mm. long, 10 mm. deep, from Lower Mohnian, Puente Hills.

the type locality. In the Girard–Mineral Springs section, an abundance of scales of this form occurs between Hoots' localities 117 and 118 (no scales have yet been collected at localities 119 to 130). *Etringus* is characterized by numerous paired transverse radii and widely spaced radii in the apical region. *Etringus scintillans* differs from the species found in the Saucesian-Zemorrian section (pl. 1, figs. 11, 11*a*) in its more elongate shape. The apical radii are longer and less numerous as compared with the number of paired transverse radii. The direction and shape of the uppermost radii are less symmetrical in the Upper Miocene species. The number of radii increases with age, as has been said before. The scales on the caudal peduncle show a greater number of transverse radii. Specimen from the Lower Modelo, Sepulveda Canyon, C.I.T. locality 317. Length 7.9 mm., depth 7.9 mm.

No. 29*a, b*. Family Clupeidae: *Xyne grex* (text fig. 5), evidently a true herring. This form was described first from the Celite quarries of Lompoc, Santa Barbara County, which are of Delmontian age, corresponding to unit 18 of the Modelo type

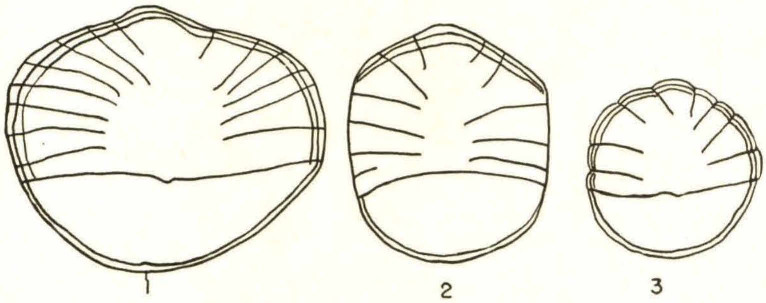



FIG. 5. *Xyne grex*. Specimens from Upper Mohnian strata. (1) Scale 8 mm. long, 9.5 mm. deep, from Girard–Mineral Springs, Santa Monica Mountains, near Hoots' locality 134. (2) Scale 7.25 mm. long, 6 mm. deep, from same locality. (3) Scale 4.2 mm. long, 4.1 mm. deep, from same locality.

locality (information supplied by Dr. M. N. Bramlette). *Xyne* is found in the Sepulveda Canyon region of the Santa Monica Mountains in the upper half of unit 9 (*Bolivina hughsi* zone). It is abundant here and seems to take the place of *Etringus*, which is not found so high as this horizon. In the Girard–Mineral Springs section *Xyne* is found abundantly at Hoots' localities 133 to 136 (corresponding to the horizon where *Xyne* is found in the eastern part of the mountains). Furthermore, *Xyne*, or a related form, is present in the Western Gulf Symons Well No. 12-17, a few hundred feet below the top of the Stevens zone. Here also the opercular bones of this form occur. The fish was found also in the Monterey hills in the vicinity of South Pasadena, and at other localities in southern California. In the scale of *Xyne* the apical part is separated from the basal part by a complete transverse line; fewer transversely paired radii are present, and these are otherwise directed than in *Etringus*. Specimens from Western Gulf Symons Well No. 12-17, at depth of 11,595–11,596 feet. Dimensions: (*a*) length 4.88 mm., depth 5.88 mm.; (*b*) length 4.59 mm., depth 4.88 mm.

No. 30. Two large species of shad, *Ganolytes cameo* and *Ganolytes aratus*, occur in Mohnian sections. *Ganolytes cameo* (pl. 3, fig. 32; text fig. 6, nos. 1, 2, 5), the older species, is much heavier and deeper. It has been described from the Lower Modelo and is very abundant there, accompanying *Etringus scintillans* in the

Sepulveda Canyon section as well as at Hoots' localities 117 and 118, Girard–Mineral Springs. *Ganolytes aratus,* described from Lompoc, is probably represented by scales and other fragments in the Upper Mohnian. The ranges of these species of *Ganolytes* may overlap in the Middle Mohnian. The two species have been described and distinguished after complete skeletons found in Upper Miocene deposits. It has not been possible so far to define the differences between their scales. The large scales of the shads are easily recognized: A varying number of irregular transverse radii are present; the ends of the radii are often marked by a row of small round depressions; these depressions generally occur in the center of the scales, especially in

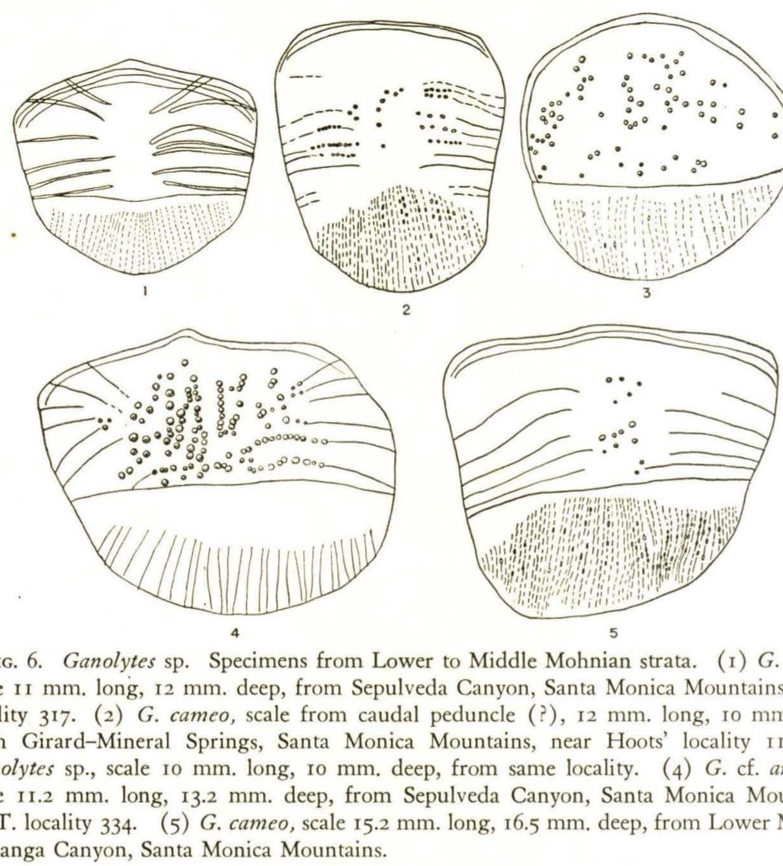



FIG. 6. *Ganolytes* sp. Specimens from Lower to Middle Mohnian strata. (1) *G. cameo,* scale 11 mm. long, 12 mm. deep, from Sepulveda Canyon, Santa Monica Mountains, C.I.T. locality 317. (2) *G. cameo,* scale from caudal peduncle (?), 12 mm. long, 10 mm. deep, from Girard–Mineral Springs, Santa Monica Mountains, near Hoots' locality 116. (3) *Ganolytes* sp., scale 10 mm. long, 10 mm. deep, from same locality. (4) *G.* cf. *aratus* ?, scale 11.2 mm. long, 13.2 mm. deep, from Sepulveda Canyon, Santa Monica Mountains, C.I.T. locality 334. (5) *G. cameo,* scale 15.2 mm. long, 16.5 mm. deep, from Lower Modelo, Topanga Canyon, Santa Monica Mountains.

larger specimens. The radii are strongest in *G. cameo.* The apical region is separated by a complete ridge and divided by numerous apical radii which may show small round depressions. Specimen of *Ganolytes cameo,* from Topanga Canyon, Modelo formation. Length 15.7 mm., depth 17.3 mm.

It is fortunate that there is an abundance of different types of herring-like fish in the horizons of the Upper Miocene, and it is hoped that these forms can be used in correlating different stratigraphic sections. It is likely that the so-called thread herring, *Opisthonema* from the Altamira shale (see David, Geol. Soc. Amer. Spec. Pub. 43, p. 84, 1943) dies out after the Middle Miocene. *Etringus* is restricted to the Mohnian stage in the Los Angeles Basin. Both evidently are warm-water types. *Xyne* and the shads range up into at least the Delmontian, but nothing like these forms exists in the North Pacific Ocean today. The shad living now in Pacific waters is a very different fish, and was introduced from the East by the U. S. Fish Commission. The shads appear first in the California Tertiary section during the Upper Saucesian stage. A species of *Ganolytes* is found more often in the Middle Miocene (see pl. 3, no. 25). True abundances of the large scales of the genus have been noticed only beginning with the Mohnian stage. It remains to be seen whether the faunal change indicated by the substitution of *Xyne* for *Etringus* in the Upper Mohnian of the Santa Monica Mountains is a general one. To make better use of these forms, it is necessary to institute a more detailed study of the species and especially to investigate the development of the scales from young fishes to adults. The age of a fish is shown on the scale by the annual rings. It is possible that young shad scales resemble those of *Xyne* to some degree. *Etringus scintillans* as a genus is well differentiated from other Mohnian forms. A different species of *Etringus* is found in the Lower Miocene (see above).

*Lower Mohnian.* The more common forms are chosen from a variety of scales found in the Lower Mohnian (pl. 4). Many of these extend up into the Upper Mohnian and Delmontian.

No. 33. Family Atherinidae: *Zanteclites* sp. *Zanteclites hubbsi* was described from the Lower Mohnian. The type having been lost, however, it is not certain that the scale belongs to this form. The scale illustrated is from Sepulveda Canyon, Lower Modelo, C.I.T. locality 317. Length 4.25 mm., depth 3.5 mm.

No. 34. Family Scombridae: *Pneumatophorus* cf. *grex.* The common mackerel from the California Upper Miocene was assigned to the Recent Atlantic species. The scale conforms with the latter. Continental Oil Company "Turnbull" No. 3, Puente Hills, at 4575 feet depth, Lower Puente. Length 3.5 mm., depth 4.1 mm. Circuli transverse, those of basal region more widely spaced. Adjacent basal and apical circuli in center almost parallel (compare with the related scales of *Sarda*). Apical radii and irregular folding present along apical margin.

No. 35. Family Thunnidae: *Sarda* cf. *stockii,* a bonito. Union Oil Company "Chapman" No. 29, at 7842–7850 feet depth, Lower Puente. Length 3 mm., depth 4.8 mm. Circuli of basal region irregularly angled and curved; in other scales (see following number) circuli become almost circular concentric.

No. 36. Same, same well at 4440–4449 feet depth, Kraemer sand (= Upper Mohnian). Length 2.5 mm., depth 4 mm.

No. 37. Family Carangidae: *Decapterus* (*Lompochites*) cf. *hopkinsi,* a jack. Continental Oil Company "Turnbull" No. 3, at 4320 feet depth. Length 3.3 mm., depth 3 mm.

No. 38. Family Carangidae: probably *Decapterus* sp. C.I.T. locality 317, Sepulveda Canyon. Length 2.06 mm., depth 1.76 mm.

No. 39. Family Sciaenidae: *Lompoquia* sp.? Girard–Mineral Springs, near Hoots' locality 117. Length 3.65 mm., depth 2.82 mm.

No. 40. Family Sciaenidae: *Lompoquia* cf. *culveri.* Girard–Mineral Springs, near Hoots' locality 117. Length 3 mm., depth 3 mm.

No. 41. Family Scorpaenidae: *Sebastodes* sp., a rock cod. C.I.T. locality 317, uppermost strata, Sepulveda Canyon. Length 5.4 mm., depth 5.4 mm.

No. 42. Family Scorpaenidae?. Girard–Mineral Springs, near Hoots' locality 117. Length 4.41 mm., depth 3.12 mm.

*Middle to Upper Mohnian.* The more common species in these zones were again chosen from the large variety of forms present (pl. 5). Jacks are very abundant (text figs. 7, 8). A species related to the living scad, family Carangidae: *Decapterus* (*Lompochites*) cf. *hopkinsi* (see text fig. 7), is the most

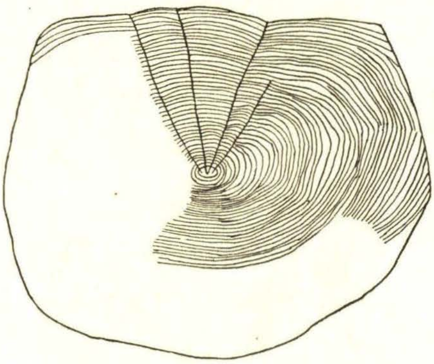


FIG. 7. *Decapterus* cf. *hopkinsi*. Scale 3 mm. long, 3.5 mm. deep, from near Hoots' locality 136.

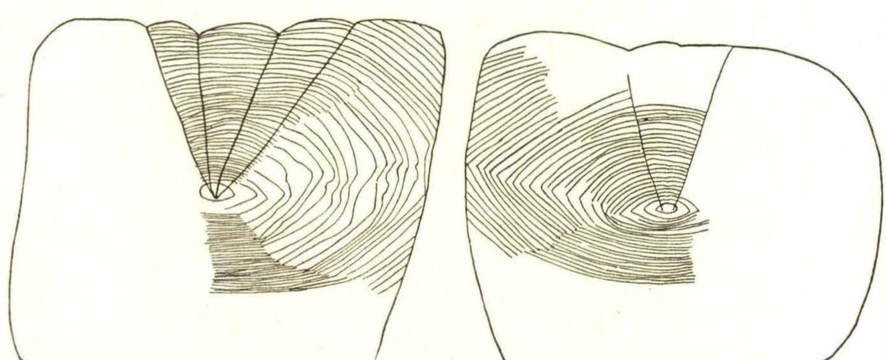



FIG. 8. Undescribed genus. (1) Scale 3.1 mm. long, 3.9 mm. deep, from Hoots' locality 134. (2) Scale 3 mm. long, 3.2 mm. deep, from Axis Company Rowland Well No. 1, at 2367–2384 feet depth.

common jack found at Hoots' locality 134, Girard–Mineral Springs. Scale hexagonal to rounded. Nucleus basad of center of scale; central circuli rounded to ovoid, dense, of small diameter; hardly angular; angles irregularly formed near outer borders of basal part of scale.

No. 43. Family Thunnidae: *Sarda* cf. *stockii*. Girard–Mineral Springs, Hoots' locality 134. Length 2.82 mm., depth 2.94 mm.

No. 44. Family Zaphlegidae: *Zaphleges* cf. *longurio.* Western Gulf Symons No. 12-17, at 11,595–11,596 feet depth. Length 2.71 mm., depth 2.94 mm. Scale rounded to oval, folded concentrically to basal part of scale. Nucleus apicad to center. Circuli symmetrically angular in apical part of scale.

No. 45. Family Pomatomidae: *Pseudoseriola* sp. Western Gulf Symons Well No. 12-17, at 11,595–11,596 feet depth. Length 3.06 mm., depth 4.88 mm. Scale quadrangular, folded concentrically to basal border. Central circuli symmetrically rectangular, their basal border rounded, apical border straight.

No. 46. Same? Same well, same depth. Length 3.82 mm., depth 2.35 mm.

No. 47. Family Thunnidae: *Sarda* cf. *stockii.* Girard–Mineral Springs, near Hoots' locality 136. Length 2.59 mm., depth 1.94 mm.

Nos. 48, 48*a*. Family Atherinidae: undescribed genus and species related to the bay smelt of California. Circuli of mid-lateral scales little extended beyond laterobasal angle; strong apical spines; laterobasal angle of lateral scales strongly acute, with circuli showing concave curvature before meeting in angle. No. 48, Girard–Mineral Springs, Hoots' locality 134; length 2.25 mm., depth 3.25 mm. No. 48*a,* Western Gulf Symons Well No. 12-17, at depth of 11,595–11,596 feet; length 2.24 mm., depth 2.65 mm.

Nos. 49, 49*a*. Family Atherinidae: undescribed genus and species. Mid-lateral scales very much deepened; laterobasal angle acute but circuli almost straight. Girard–Mineral Springs, Hoots' locality 136. No. 49, length 1.37 mm., depth 4.00 mm. No. 49*a,* length 2.12 mm., depth 2.47 mm.

No. 50. Family Sparidae: *Rhythmias* sp. Scales with strong basal folds, circuli directed toward dorsal and ventral margin, generally no marginal spines. Western Gulf Symons Well No. 12-17, at depth of 11,595–11,596 feet. Length 2.19 mm., depth 3.53 mm.

Nos. 51, 51*a*. Family Sciaenidae: *Lompoquia* cf. *culveri.* Girard–Mineral Springs, Hoots' locality 134. No. 51, length 3.17 mm., depth 3.46 mm. No. 51*a,* length 4.06 mm., depth 3.71 mm.

No. 52. Undetermined. Girard–Mineral Springs, Hoots' locality 134. Length 6.29 mm., depth 8.23 mm.

No. 53. Family Sciaenidae: *Lompoquia* sp. Girard–Mineral Springs, Hoots' locality 134. Length 3.06 mm., depth 2.65 mm.

A small lantern fish is found abundantly represented in the uppermost Mohnian of the Los Angeles Basin. The entire fish is found rather than its scales, indicating deep neritic to bathyal surroundings of deposition. This fish and *Bathylagus,* another bathyal form, were found along the northern rim of the Santa Monica Mountains at C.I.T. localities 326, 329, and 379 in the region of Sepulveda Canyon, and at Hoots' localities 136 and 142 of the Girard–Mineral Springs section.

## *Delmontian and Pliocene*

No material has been studied from the Delmontian. P. P. Goudkoff's fish-scale zone lies in this stage (see Bull. Geol. Soc. Amer., vol. 50, p. 1950, 1939). The fossil fish fauna from Lompoc, the richest known from the Pacific coast area, is of Delmontian age.

Pliocene deposits have not been studied. Good scales occur in the Repetto formation of southern California. In general the lithology of the Pliocene is such as to appear unfavorable to the preservation of scales, but fish vertebrae are encountered from time to time.

## Summary of Known Tertiary Silversides

The scales of the silversides, family Atherinidae, with their very distinct laterobasal angle and the deepened mid-lateral scales, are easily distinguished from those of all other groups. They are also sufficiently abundant to be of use in correlation. Four species, possibly five, found in different California Tertiary sections, are compared on plate 6. Another is shown in text figure 9.

Form 1 (figs. 1, 1*a*), from the Upper Zemorrian. Same as nos. 14, 14*a*, plate 2.

Form 2 (fig. 2), from the Lower Mohnian and probably Relizian, *Zanteclites* ?. Same as no. 33, plate 4.

Form 3 (figs. 3, 3*a*, 3*b*), from the Upper Mohnian, San Joaquin Valley, Western Gulf Symons Well No. 12-17, at depth of 11,595–11,596 feet. Fig. 3, scale 1.2 mm. long, 2.8 mm. deep; fig. 3*a*, same as no. 48*a*, plate 5; fig. 3*b*, scale 2 mm. long, 1.7 mm. deep.

Form 4 (figs. 4, 4*a*), from the Upper Mohnian, Girard–Mineral Springs, Hoots' locality 134. Fig. 4, 2 specimens, upper partly superimposed on lower, upper same as no. 48, plate 5; fig. 4*b*, scale 2.1 mm. long, 2.2 mm. deep.

Form 5 (figs. 5, 5*a*), from the Upper Mohnian, Girard–Mineral Springs. Same as nos. 49, 49*a*, plate 5.

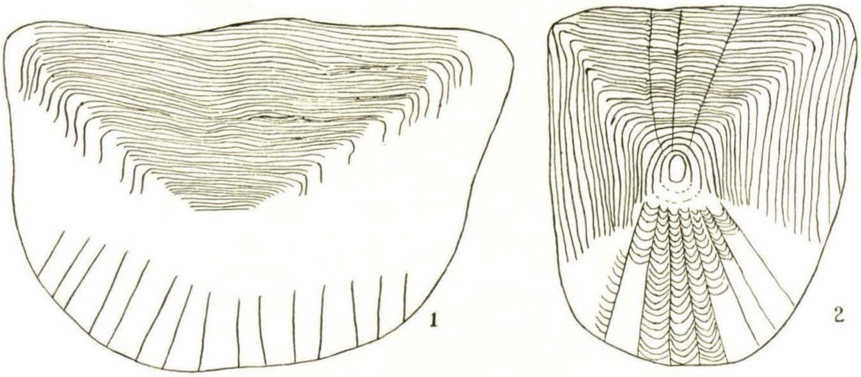



Fig. 9. *Zanteclites* sp. Specimens from McLure shale, San Joaquin Valley, Ohio Oil Company "Bear State" Well No. 23. (1) Scale 4 mm. long, 5 mm. deep, from 4636 feet depth; × 12. (2) Scale 3.1 mm. long, 2.8 mm. deep, from 4477 feet depth; × 14.

Form 6 (text fig. 9), from the Upper Mohnian, *Bolivina brevior* zone. Ohio Oil Company "Bear State" Well No. 23, Sec. 30, T. 28 S., R. 21 E. This is the largest silversides scale found so far; it is characteristic for the McLure shale of the San Joaquin Valley. Circuli always denser in central sector of basal part of scale. In the deep lateral scales circuli may or may not be present in dorso- and ventrobasal sectors; if present they are irregular and more or less shortened.

## Conclusions

Determinable fossil fish remains in California are undoubtedly abundant and of considerable variety as to type. The foregoing report shows that well characterized remains are readily available and can be expected in all parts of the Tertiary section. Hard, shaly diatomaceous deposits are the most favorable for fish-scale preservation, and in shale units of certain formations scales are the most readily available fossils for correlation.

Fish scales have sufficient characterization and are large enough to be used in the field. At certain horizons in the stratigraphic sequence an abundance of specific types of scale is present; where they occur in any number they cannot be overlooked, and can be recognized with a small magnifying glass.

As in the instance of fossil foraminifera, particular kinds of scale distinguish certain parts of the geologic column. The differences noted are due in part to facies changes, and in part to more general faunal changes that have taken place with the lapse of time. Fossil fishes furnish evidence by which the ecological conditions during deposition of marine rocks can be definitely determined. Most fishes are restricted to certain environments as regards temperature and depth, and are therefore unlike many foraminifera, which can live just as well in cold as in deep water. Fish-scale assemblages can be readily identified as to their abyssal, bathyal, neritic, or littoral character. When the assemblages become better known, evaluation of the different factors involved will give even more definitive information as to ecological conditions. In this respect the scales supply a satisfactory check on the zoning established through use of the foraminifera, and aid in a better recognition of the size and extent of ancient sea basins.

Utilization of fossil fish scales permits the division of geologic time into units probably somewhat larger than stages. Scales are of special use in horizons where a definite faunal change has occurred. Such changes do not seem to coincide with the divisions that have been established by use of the foraminifera. The number of different types of fish remains is not extremely great. The best results in solving problems of correlation of strata can doubtless be obtained when fossil fish scales are utilized along with foraminifera. The degree of abundance of different kinds of fish should likewise furnish reliable information, once these forms have been identified.

Valuable data relating to problems of sedimentation and oceanography can be obtained from a study of the type of material discussed in this paper. Presence or absence of fresh-water outlets and strength and direction of oceanic currents along the border of the marine basin are indicated by the composition of the scale assemblages.