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TAXONOMY AND BIOSTRATIGRAPHY OF CONIACIAN THROUGH MAASTRICHTIAN *ANCHURA* (GASTROPODA: APORRHAIIDAE) OF THE NORTH AMERICAN PACIFIC SLOPE

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ABSTRACT—North American Pacific Slope deposits of Coniacian to Maastrichtian age have yielded eight biostratigraphically useful species of *Anchura*: *A. (Helicaulax?) popenoei* new species, Coniacian; *A. halberdopsis* new species, early Campanian; *A. callosa* Whiteaves, 1903, early Campanian; *A. falciformis* (Gabb, 1864), late early to middle Campanian; *A. phaba* new species, middle to late Campanian; *A. ainikta* new species, middle to late Campanian; *A. gibbera* Webster, 1983, late Campanian to early Maastrichtian; *A. baptos* new species, late Maastrichtian to early Danian. In addition, two other possible species are *A. nanaimoensis* (Whiteaves, 1879), middle to late Campanian, and *Anchura?* new species, late Maastrichtian. These species together with two additional Turonian species, *A. (Helicaulax) tricosa* Saul and Popenoe, 1993, and *A. (H.) condoniana* Anderson, 1902, allow the definition at least eight Late Cretaceous *Anchura* zones for the Pacific Slope. These zones have durations of 1.5 m.y. to 4 m.y.

Anchura (H.?) popenoei from northern California appears most closely related to *A. (Helicaulax) tricosa* Saul and Popenoe, 1993, of Turonian age from southern California. *Anchura callosa, A. falciformis, A. nanaimoensis,* and *A. phaba* appear to be closely related based on sculptural elements, as does *A. gibbera* despite having an anterior spur on the wing. However, these species appear to belong to two latitudinally differentiated faunal provinces. Species having a northern range include *A. callosa, A. falciformis,* and *A. nanaimoensis,* whereas *A. phaba* and *A. gibbera* are from more southern deposits, as are also *A. halberdopsis, A. ainikta,* and *A. baptos.*

INTRODUCTION

THE HIGH-SPIRED aporrhaid *Anchura* is one of the more widely distributed gastropods of Late Cretaceous age from Pacific Slope deposits. The genus is known from rocks as old as the late Early Cretaceous and ranges into early Paleocene age rocks on the Pacific Slope. One to several species of *Anchura* were present at any one time throughout much of the Late Cretaceous, giving it biostratigraphic utility comparable to that of *Turritella.* In addition, some species appear to have been geographically constrained, providing some paleobiogeographic information in this tectonically complex region. *Anchura* is generally less common than *Turritella* but may be locally abundant. Specimens are usually more abundant in fine-grained sandstone or siltstone facies representing middle to outer shelf environments, where they may be the only biostratigraphically useful fossil present. In contrast, *Turritella* is typically more abundant in slightly coarser-grained deposits than those yielding *Anchura,* possibly reflecting a more nearshore or shallower water habitat for the former. *Anchura halberdopsis* and *A. (H.) condoniana,* which resemble one another, have been recovered from coarser-grained sediment than the other species.

Anchura is characterized by complex morphological features that allow it to be readily broken down into species and evolutionary lineages. These features include complex ornamentation, typically of both axial and spiral sculpture, a variable outer lip and wing that develop processes, and whorl peripheries that may develop one or more carinae. Regardless of the potential to subdivide the Pacific Slope *Anchura* based on these features, most previously documented Campanian and Maastrichtian age specimens from the West Coast have been assigned to *Anchura falciformis* (Gabb, 1864). However, this study indicates that *A. falciformis,* which was described from specimens collected from the top of the Chico Formation on Chico Creek, Butte County, California, is confined to rocks of late early and middle Campanian age. Other previously described Campanian and Maastrichtian age species are *A. callosa* Whiteaves, 1903, probably from the Cedar District Formation (Ward, 1978) on Vancouver Island, British Columbia, *A. gibbera* Webster, 1983, from the Rosario Formation near Santa Catarina Landing, Baja California, Mexico, and *"Potamides tenuis" nanaimoensis* Whiteaves, 1879, which is undoubtedly an *Anchura,* but is based upon immature specimens.

Several additional Late Cretaceous *Anchura* species have been documented from the Pacific Slope. Anderson (1958) listed four species, of which only *A. falciformis* is discussed herein. None of the other three is a typical *Anchura*; two, *"Anchura" angulata* (Gabb, 1864) and *"Anchura" biangulata* Anderson, 1938, are probably of Albian and Cenomanian age, and *"A." carinifera* Gabb, 1869, may be of early Tertiary age. *"Anchura" carinifera,* based on a very small specimen, is comparable to *Teneposita* Loch, 1989, in size, but the spire has indications of spiral sculpture only and lacks the arcuate axial ribbing of *Teneposita* and juvenile *Anchura.* Saul and Popenoe (1993) discussed two species of Turonian age, *A. (Helicaulax) condoniana* (Anderson, 1902) and *A. (H.) tricosa* Saul and Popenoe, 1993. *"Alaria" fairbanksi* Davis, 1913, from near Slates Hot Springs is possibly of late Campanian age based upon *Baculites* specimens from that vicinity (Matsumoto, 1960, p. 74). Davis thought the species to be congeneric with *Anchura stenoptera* of Whiteaves, 1879 (= *A. callosa* Whiteaves, 1903, from Vancouver Island, British Columbia), but it bears a stronger resemblance to *Tessarolax* Gabb, 1864, than to *Anchura.*

Within the Coniacian to Maastrichtian interval, we recognize nine *Anchura* species, five of them new. Figure 1 illustrates the stratigraphic ranges of these species relative to Pacific Slope ammonite and *Turritella* zonations that have been calibrated to the recently revised geochronology and chronostratigraphy of Obradovich (1993) and Gradstein et al. (1994). Identified *Anchura* species are as follows: *A. (H.?) popenoei* new species, Coniacian; *A. halberdopsis* new species, early Campanian; *A. callosa* Whiteaves, 1903, early and early middle Campanian; *A. falciformis* (Gabb, 1864), middle Campanian; *A. phaba* new species, late middle and late(?) Campanian; *A. ainikt*a new species, late middle and late Campanian; *A. gibbera* Webster, 1983, late Campanian and early Maastrichtian, and *A. baptos* new species, late Maastrichtian. Two additional species may occur,

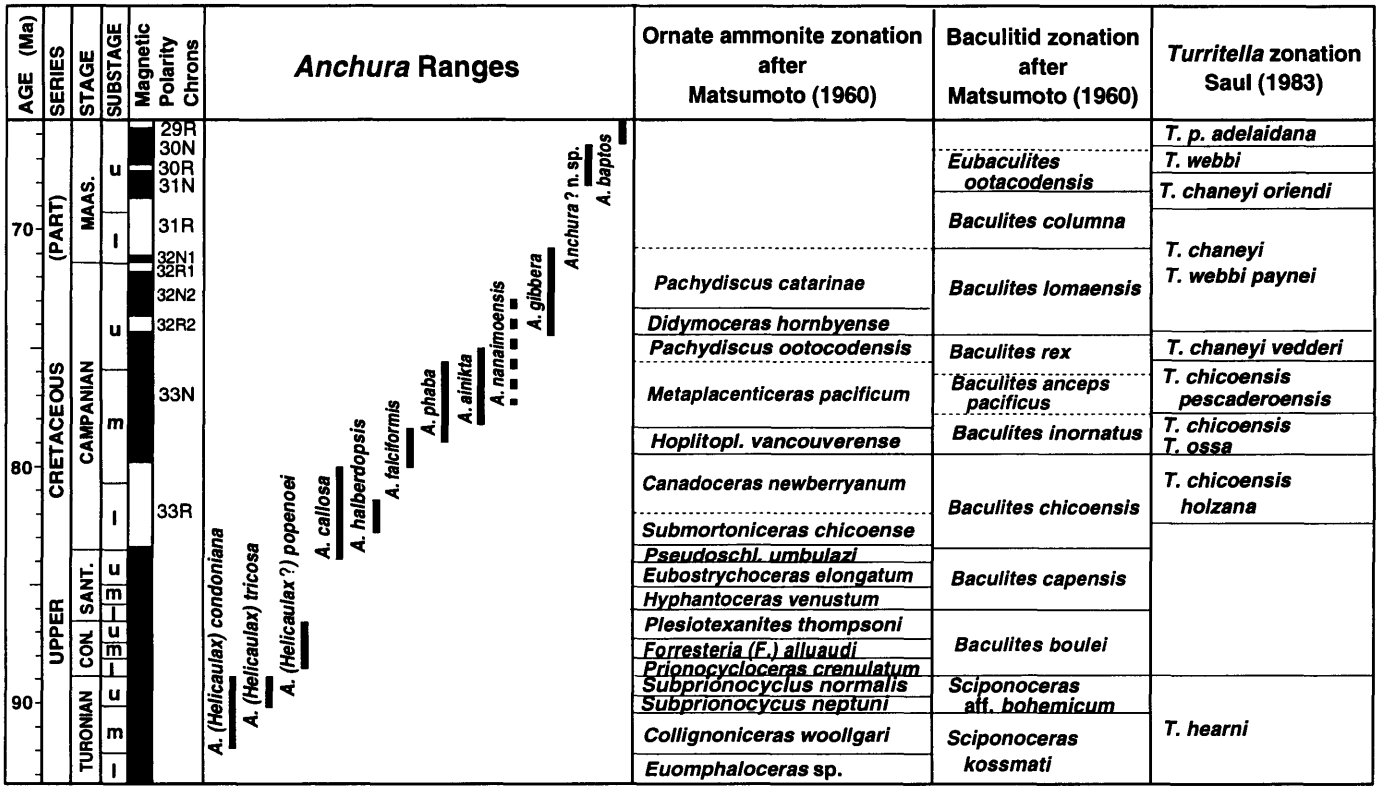

FIGURE 1—*Anchura* ranges plotted against time, rock-stratigraphic units, magnetostratigraphy, and Pacific Slope ammonite and *Turritella* zones. Ages of stage boundaries based on Obradovich (1993). Magnetic polarity chronology based on Verosub et al. (1989) and Bannon et al. (1989) for ties to Pacific Slope biostratigraphy and Gradstein et al. (1994) for ties to geochronology and chronostratigraphy. Ammonite genera abbreviations are *Hoplitopl.* for *Hoplitoplacenticeras* and *Pseudoschl.* for *Pseudoschloenbachia.*

A. nanaimoensis (Whiteaves, 1879), of middle or late Campanian age, based on juveniles, and an incomplete specimen of late Maastrichtian age referred to *Anchura?* new species. The geochronologic data indicate that most of these species had durations of 2 to 3 m.y.; but some apparently ranged as long as 4 m.y. or as short as 1.0 to 1.5 m.y. (Figure 1). These durations are consistent with the 2.0 to 2.5 m.y. ranges estimated by Sohl (1977) for Western Interior and Gulf Coast species of the aporrhaid genus *Drepanochilus.*

Some of the species noted in this study display restricted geographic distributions. For example, *A. callosa* and *A. falciformis,* which are found from the Sacramento Valley northward to Puget Sound, are not recognized from southern California deposits of appropriate age. Instead, *Anchura halberdopsis* is restricted to southern California rocks of early Campanian age, and *A. phaba* occurs widely in southern California strata of middle and early late Campanian age and is only found to the west of the San Andreas fault as far north as the Pigeon Point area, San Mateo County, California. *Anchura gibbera* also has a southern distribution, having been found from San Diego County, California, south to Arroyo Santa Catarina, Baja California, Mexico.

MORPHOLOGIC OBSERVATIONS AND COMPARISONS

Protoconchs have been found for some of the species discussed herein. All have about four apparently smooth whorls. The earliest teleoconch whorls, herein referred to as juvenile whorls (usually two), have fine arcuate axial sculpture, concave toward the aperture. Juvenile whorls have at least one and a half times as many of these axial ribs per whorl as do the adolescent whorls. On the adolescent whorls, the spiral sculpture becomes obvious, and an angulation or carina usually develops on one of the spiral cords.

The juvenile and adolescent whorls of *Anchura (Helicaulax?) popenoei A. halberdopsis,* and *A. ainikta,* have randomly occurring varices. Similar varices also are present on the Turonian *A. (H.) tricosa* Saul and Popenoe, 1993. *Anchura (H.?) popenoei* and *A. (H.) tricosa* have several other characteristics in common, but the other two species are not otherwise notably similar; *A. halberdopsis* bears a greater resemblance to *A. (Helicaulax) condoniana* (Anderson, 1902) than to *A. (H.) tricosa.* Varices are not mentioned in the descriptions or discussions of any Gulf Coast species (Wade, 1926; Sohl, 1960; Dockery, 1993), but *A. substriata* Wade, 1926, from the Ripley Formation along Coon Creek, Tennessee, has varices on its early whorls (see Sohl, 1960, p. 106, plate 12, figures 2–3). Varices are considered to be of little or no systematic importance within the closely related Strombidae family by Davies (1971, p. 328), but Abbott (1960, p. 34) found certain types of varices to be typical of some subgenera in the genus *Strombus* Linnaeus, 1758. Abbott additionally suggested that the varices served to strengthen the fragile juvenile shell. Among the Pacific Slope species these varices have not been found on specimens of *A. callosa, A. falciformis, A. phaba,* and *A. gibbera.*

Anchura callosa, A. falciformis, A. phaba, and *A. gibbera* may form a lineage from oldest to youngest, even though they display disjunct distributions. All four species have two strong cords anterior to the carina. The sculpture of the spires in these species

consists of somewhat curved, round-topped axial ribs with interspaces wider than the ribs. The axial rib number appears to increase through time. The axial ribs are crossed by narrower spiral cords, which also have interspaces wider than the cords. The axial ribs tend to be weakest posteriorly and strongest at the periphery. The profile of the anterior portion of the outer lip is slightly scalloped. *Anchura callosa* and *A. falciformis* are very similar, and *A. callosa* grades morphologically into *A. falciformis* within the Chico Creek section. Whiteaves' (1879) figure of an *Anchura* from Vancouver Island, British Columbia, that he first identified with *A. stenoptera* (Goldfuss, 1844) and later renamed *A. callosa* Whiteaves, 1903, is similar to *A. falciformis,* although Whiteaves did not compare the Vancouver Island species to *A. falciformis. Anchura callosa* appears to be the species figured as *A. falciformis* by Taff, Hanna, and Cross (1940), and *A. callosa* occurs in the Tenmile Member (Haggart and Ward, 1984) of the Chico Formation on Chico Creek, Butte County, from about 548 m to about 915 m above the base of the section. Large specimens of *A. falciformis* are common near the top of the Tenmile Member of the Chico Formation on Chico Creek, and from the Chico Formation on Butte Creek and near Pentz, Butte County, California. *"Potamides tenuis" nanaimoensis* Whiteaves (1879) is an *Anchura* very similar to *A. falciformis* and *A. phaba,* but the type specimens are too immature either to separate *A. nanaimoensis* with certainty from these species or to combine it with one of them.

SYSTEMATIC PALEONTOLOGY

Morphologic terminology used and parameters measured in this paper are shown in Figure 2. Terminology for the extended outer lip of *Anchura* is that of Dockery (1993). The *shank* extends laterally from the body whorl and bears a *posterior arm* that extends posteriorly as a long spine or spur. The shank may bear an *anterior arm,* which is generally a short spur extending anteriorly from the terminus of the shank's anterior margin. Measurement abbreviations and symbols used in Tables 2–11 are: H = height of specimen; Hp = height of penultimate whorl, in immature specimens the largest whorl bounded by sutures; Db = diameter of largest whorl available, in mature specimens the body whorl; Dp = diameter of whorls measured for Hp; Dp/Hp = ratio of whorl width to whorl height; R = length of rostrum, uncertain that any are complete; PA = pleural angle, measured along spire whorls, excluding body whorl; S = shank length, from posterior outer lip inboard of sulcus, parallel to keel, to point of greatest flexure of keel; Ct = total number of primary spiral cords on a spire whorl; Cp = cords posterior to angulation or carina of whorl; A = axial ribs, counted on whorl measured for Hp; † = crushed; ● = ribs counted on half whorl and doubled.

Institutional abbreviations used in this paper are: ANSP = Academy of Natural Sciences of Philadelphia; CASG = California Academy of Sciences, Geology; CIT = California Institute of Technology; GSC = Geological Survey of Canada; IGM = México Museo del Paleontologia del Instituto de Geología; LACMIP = Natural History Museum of Los Angeles County, Invertebrate Paleontology; UCLA = University of California, Los Angeles; USGS = United States Geological Survey; USNM = United States National Museum; UWBM = University of Washington, Burke Museum.

Superfamily STROMBACEA Rafinesque, 1815
Family APORRHAIDAE Gray, 1850
Genus ANCHURA Conrad, 1860

Type species.—*Anchura abrupta* Conrad, 1860, by monotypy, from the Gulf Coast Maastrichtian.

Diagnosis.—Medium- to large-sized aporrhaids with high, evenly tapering spires; sculpture ornate, with both axial and spiral elements, commonly noded at intersections; aperture sublenticular; anterior rostrum long and narrow; outer lip elongate, extended into a falcate wing, bent posteriorly.

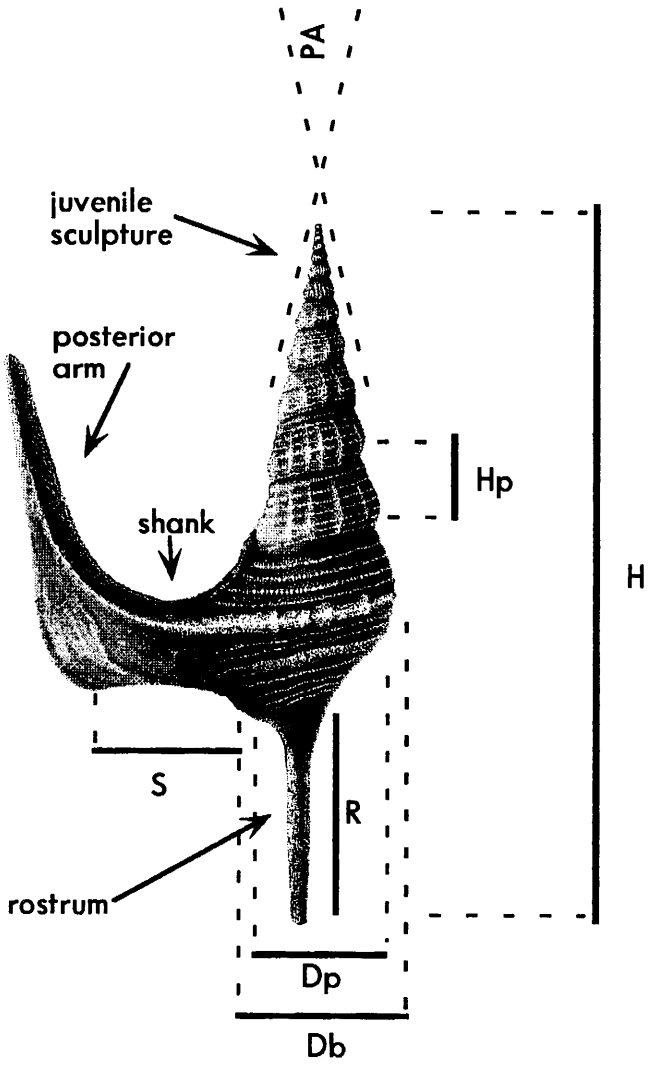

FIGURE 2—Morphology of *Anchura* and diagram of features measured.

Discussion.—The above diagnosis differs from that of Sohl (1960, p. 104) and Dockery (1993, p. 62) in omitting reference to an anterior arm or lobe on the wing. This is the projection that gives Conrad's original illustration its T-shaped wing. Among Pacific Slope species only *Anchura gibbera* is known to have such an anteriorly directed extension. *Anchura falciformis* has a broad, rounded expansion at the posteriorward bend of the wing, which is similar to that of *A. corniculata* Dockery, 1993, from the Campanian of the Gulf Coast.

Dockery (1993) has described the protoconch of *A. chapelvillensis* Dockery, 1993, from the Coffee Sand of Mississippi, as having the last one and a quarter whorls smooth but with a rounded carina or shoulder. Transition to the teleoconch is abrupt, and the first few whorls are carinate and sculptured with eight spiral lirae, the fourth abapical spiral forming the carina and fine opisthocline ribs that are concave toward the aperture. The next four adolescent whorls are evenly convex and are sculptured with eight strong spiral lirae and weaker opisthocline ribs. Although there are similarities to the pattern of develop-

TABLE *1*—Comparative tabulation of some characteristics of species of *Anchura* and *A. (Helicaulax)*. Whorl profiles that are straight to slightly curved are listed as straight. The number under "angulate" indicates the placement of the angulation, and for *A. callosa* the position of maximum curvature: 2 = mid whorl, 3 = anterior third line of whorl, 4 = anterior quarter line. Pleural angles are averaged from those in Tables 2–11. Whorl diameter/height ratios are averaged from Dp/Hp ratios of Tables 2–11. *Anchura baptos* and *A.?* new species have axial ribs on less mature whorls only. The axial rib category "straight" includes slightly arcuate ribs. Cord count is from a spire whorl, posterior is the number of cords posterior to the angulation, maximum curvature, or strongest cord (=Cp of Tables 2–11); total is the suture to suture number of cords (=Ct of Tables 2–11). Standard deviation (±) of averages reflects post-depositional damages as well as variation.

Species of *Anchura* and *Anchura (Helicaulax)*	Number of specimens	Whorl profile			Pleural angle	Whorl diam/ht ratio	Varices	Axial ribs			Spiral cords	
		Straight	Rounded	Angulate				Arcuate	Straight	Number	Posterior	Total
A. baptos new species	1			XXX 2	28°	1.9					1	3
A.? new species	1		XXX		18°	1.8						
A. gibbera Webster	3			XXX 2	23° ± 3.6	1.5 ± 0.02					2	4
A. nanaimoensis (Whiteaves)	3			XXX 2	20° ± 1.5	1.7		XXX		14	3 ± 0.0	8 ± 0.6
A. ainikta new species	5			XXX 2	18° ± 1.3	1.6 ± 0.26	XXX	XXX		14 ± 1.0	1 ± 0.0	4 ± 0.0
A. phaba new species	10			XXX 3	25° ± 3.4	1.7 ± 0.15		XXX		18 ± 2.3	3 ± 0.4	6 ± 1.0
A. falciformis (Gabb)	8			XXX 3	24° ± 2.6	1.7 ± 0.11			XXX	13 ± 1.5	4 ± 0.4	8 ± 0.5
A. halberdopsis new species	7	XXX			25° ± 2.8	2.0 ± 0.22	XXX		XXX	13 ± 1.8	3 ± 0.8	6 ± 0.4
A. callosa Whiteaves	14		XXX	2	21° ± 1.2	1.6 ± 0.77		XXX		13 ± 1.6	4 ± 0.7	8 ± 1.1
A. (H.?) popenoei new species	1			XXX 3	22°	2.0	XXX	XXX		18	2	6
A. (H.) tricosa Saul and Popenoe	7			XXX 4	26° ± 2.7	1.8 ± 0.14	XXX	XXX		15 ± 1.0	3 ± 0.0	6 ± 0.6
A. (H.) condoniana (Anderson)	6	XXX			35° ± 3.3	2.0 ± 0.22			XXX	20 ± 0.9	4 ± 0.5	7 ± 0.8

ment in Pacific Slope *Anchura, A. chapelvillensis* differs in having the juvenile whorls carinate rather than rounded, and the earliest adolescent whorls rounded rather than angulate, as seen in *A. callosa, A. falciformis, A. nanaimoensis,* and *A. gibbera.*

In the type species of *Anchura,* the shank is without posterior or anterior secondary spurs. Saul and Popenoe (1993) mistakenly suggested that typical *Anchura* be confined to species with no secondary spurs on the shank of the outer lip and having the anterior rostrum deflected to the left in apertural view. These features are, apparently only of specific importance, for Dockery (1993) has illustrated species of *Anchura* from the Campanian of Mississippi that have undeflected rostra and secondary spurs along the shank. Although the shanks of Pacific Slope Turonian species *Anchura (Helicaulax) condoniana* and *A. (H.) tricosa* Saul and Popenoe, 1993, have secondary spurs, none of the Pacific Slope Coniacian to Maastrichtian species discussed herein is known to have secondary spurs on its shank despite Gabb's (1864, 1868) original illustration of *A. falciformis* showing a secondary spur on the anterior edge of the shank. *Anchura abrupta* has the anterior rostrum deflected to the left in apertural view; the rostra of West Coast species *A. callosa, A. falciformis, A. phaba, A. ainikta, A. gibbera,* and *A. baptos* are not so deflected, but the rostrum of *A. falciformis* is bent slightly backward.

Some important characteristics used in differentiating Pacific Slope species of *Anchura* are tabulated in Table 1. Among the species included in this paper *Anchura halberdopsis* is most similar to *A. abrupta* in its sculpture. *Anchura callosa, A. falciformis, A. phaba,* and *A. gibbera* form a group, the *Anchura falciformis* group, having two strong cords anterior to the carina, spire sculpture of more or less arcuate, round-topped axial ribs crossed by narrower spiral cords, the axial ribs weakest posteriorly and strongest at the periphery, the anterior portion of the outer lip profile slightly scalloped, the aperture with a thick callus pad posterior to the basal sinus. *Anchura nanaimoensis* probably also belongs to this group. *Anchura ainikta, A. baptos,* and *Anchura?* new species are dissimilar. *Anchura (H.?) popenoei* is most similar to *A. (H.) tricosa,* although its sculpture also is rather similar to that of *A. callosa.*

Age.—The total age range of *Anchura* is poorly understood and in need of reevaluation, as many forms previously assigned to the genus do not belong to it (see Sohl, 1960, p. 105). The genus appears to be constrained to the Late Cretaceous in the Gulf Coast region of North America (Sohl, 1960), but, on the Pacific Slope, undocumented species of *Anchura* apparently occur in the Early Cretaceous and *A. baptos* ranges into the Paleocene.

ANCHURA HALBERDOPSIS new species
Figure 3.1–3.4

Diagnosis.—A relatively small *Anchura* with strong, nearly straight costae on the spire and randomly occurring varices on the early whorls. Falcate outer lip strong and shaped like a halberd.

Description.—Shell medium-sized, high-spired, pleural angle about 30 degrees, drawn out anteriorly into anterior rostrum; whorl gently, unevenly rounded becoming slightly angulate on penultimate whorl and strongly angulate on last whorl; whorls about eight in number; suture appressed; protoconch unknown; varices randomly present on juvenile and adolescent whorls; growth line antispirally concave on spire. Mature sculpture strong, of both axial ribs and spiral cords; axial ribs nearly straight on spire, strongest on early whorls, weakening on body whorl, 11–13 on penultimate whorl, forming nodes where crossed by spiral cords, strong nodes developed on angulation of last whorl; spiral cords stronger on penultimate and ultimate whorls, four to five cords showing on spire whorls, fourth cord strongest, forming

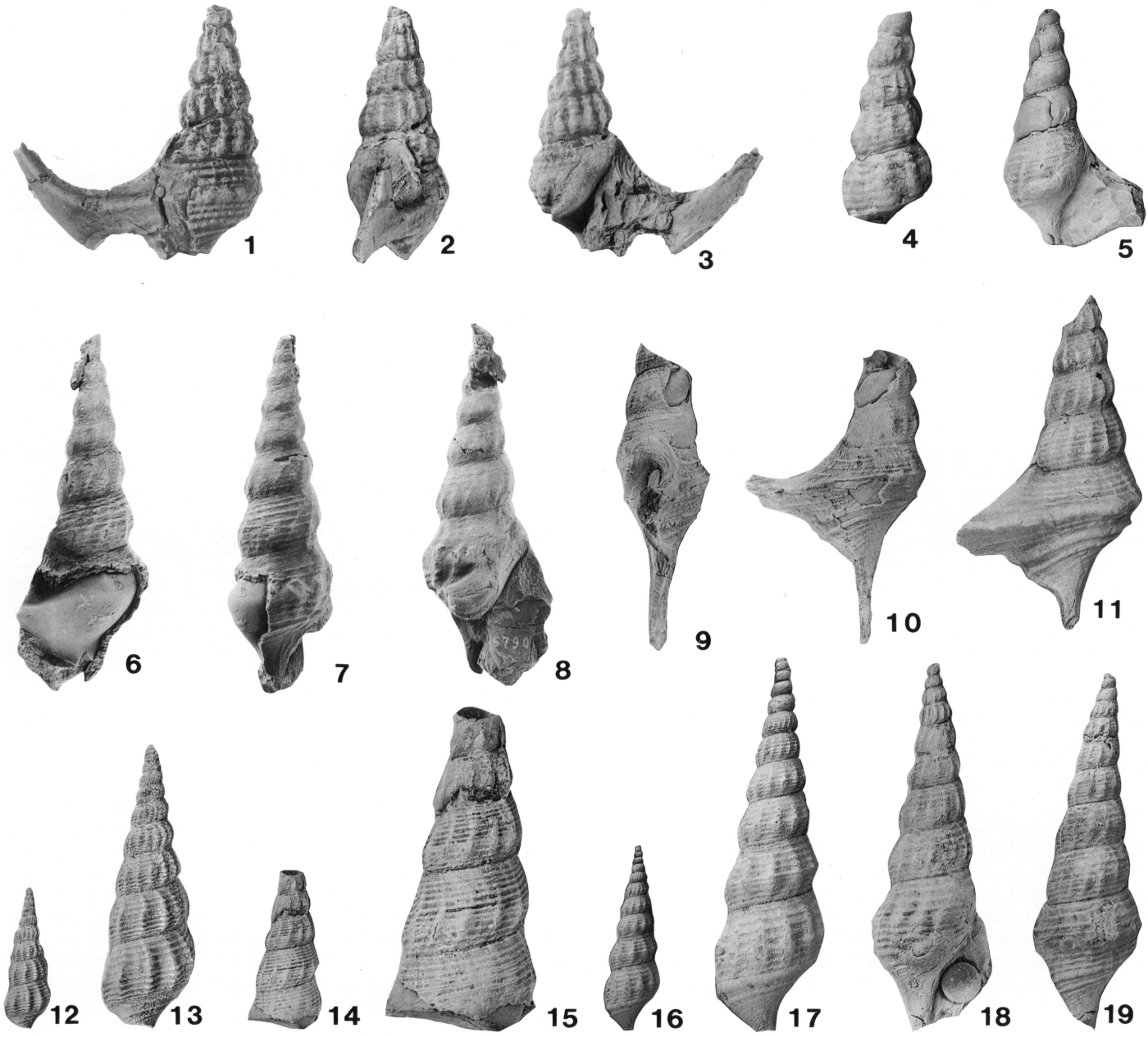

FIGURE 3—*1–4, Anchura halberdopsis* new species. *1–3,* Holotype, abapertural, side, and apertural views, ×1, LACMIP 11305, locality CIT 1053; *4,* paratype, spire showing varices, ×1.5, LACMIP 11311, locality CIT 1053. *5–19, Anchura callosa* Whiteaves. *5,* Hypotype, apertural view, ×1, LACMIP 11315, locality UCLA 3637; *6–8,* holotype, abapertural, side, and apertural views, ×1, GSC 5790; *9, 10,* hypotype, side and abapertural views, ×1, LACMIP 11314, locality UCLA 3637; *11,* hypotype, abapertural view, ×1, LACMIP 11344, locality 3643; *12, 13,* hypotype, abapertural view, ×1 and ×2, LACMIP 11313, locality UCLA 3635; *14, 15,* hypotype, abapertural view, ×1 and ×2, LACMIP 11317, locality UCLA 3637; *16, 17,* hypotype, abapertural view, ×1 and ×2, LAMCIP 11319, locality UCLA 3643; *18, 19,* hypotype, apertural and abapertural views, ×1, LACMIP 11312, locality UCLA 3635.

a noded keel on ultimate whorl and extending onto shank as carina; six to seven cords anterior of keel on ultimate whorl, third cord usually strongest; juvenile sculpture of closely spaced arcuate axial ribs on at least two whorls. Outer lip expanded into ax-shaped wing, anterior margin angulate (near 90 degrees) at posteriorward bend, thickened internally and filled with callus; posterior end of wing tilted near 15 degrees abaperturely to axis of spire. Aperture with moderately thick, broad inner lip extending apically almost to previous suture. Thick, sinuous, elongate callus pad formed on base along inner lip edge.

Remarks.—Although two dozen specimens are available, the rostrum is not preserved on any specimen, nor is the entire outer edge of the lip between the keel and the rostrum. The cords anterior to the keel on the ultimate whorl are of variable strength; commonly the third is strongest, but the third and fourth or the third, fourth, and fifth may be about equally strong and stronger than the other cords.

The thickened wing of this species with its angled anterior outline at the posteriorward bend is very different from those of *A. callosa* and *A. falciformis,* which are broader, less thick-

TABLE 2—Measurements in mm of *Anchura halberdopsis* new species. For abbreviations and symbols used, see introduction.

Specimen	H	Hp	Db	Dp	Dp/Hp	R	PA	S	Ct	Cp	A	Remarks
LACMIP 11305	38.2	7.0	17.0	13.8	1.97	—	26°	15.5	6	4	13	body + 5 whorls
LACMIP 11306	37.5	6.8	13.0†	12.8	1.88	—	27°	17.0	6	3	16	body + 6 whorls
LACMIP 11307	30.3	6.1	15.8	13.0	2.13	—	27°	—	5	2	13	body + 4 whorls
LACMIP 11308	37.0	6.2	—	12.6	2.03	—	22°	—	7	3	14	penult. + 6 whorls
LACMIP 11309	33.4	6.6	17.2	13.6	2.06	—	28°	—	6	2	13	body + 4 whorls
LACMIP 11310	29.8	6.5	17.5	13.5	2.08	—	27°	—	6	3	14	body + 3 whorls
LACMIP 11311	16.8	3.8	8.1	6.2	1.63	—	21°	—	7	—	10	juv. 5 whorls

ened, and have a more roundly expanded anterior margin at the posteriorward bend. The wing of *A. halberdopsis* is essentially similar to that of *A. abrupta* (see Sohl, 1960, plate 12, figures 1 and 4), but the former has a much shorter posterior arm, and the anterior arm is represented by little more than an abrupt angulation. The varices on the early whorls occur irregularly and are inconsistent in number; LACMIP 11311 consists of five whorls and has seven varices. The inner lip callus of *A. halberdopsis* is relatively thicker and extends higher on the apertural face than that of *A. callosa* or *A. falciformis,* reaching almost to the previous suture. The callus pad of *A. halberdopsis* is, however, less thick than that of *A. callosa, A. falciformis, A. phaba, A. gibbera,* or *A. baptos. Anchura halberdopsis* is stouter than *A. callosa.* None of the mature specimens of *A. halberdopsis* is as large as winged specimens of *A. falciformis* or *A. phaba,* and its sculpture is relatively rougher with a stronger axial component. *Anchura halberdopsis* has at least four cords, one of which is strongest, instead of the pair of strong basal cords characteristic of *A. callosa, A. falciformis, A. phaba,* and *A. gibbera.* The pattern of sculpture on *A. halberdopsis* more closely resembles that of *A. abrupta* than does the sculpture of *A. falciformis* or *A. phaba.* The sculpture of *A. halberdopsis* is still more similar to that of *A. (H.) condoniana,* differing mainly in the former having fewer axial ribs per whorl. *Anchura halberdopsis* also resembles *A. (H.) condoniana* in spire height, pleural angle, whorl profile, and in having a strongly noded keel on the ultimate whorl. *Anchura halberdopsis* differs in lacking the posterior digitation on the outer lip (but the posterior digitation is inconsistently developed in *A. (H.) condoniana*), in having varices on the early whorls, straighter axial ribs than those of condoniana, and in having a shorter shank to the wing, a more posteriorly directed posterior arm, and more of an anterior arm. As in *A. (H.) condoniana, A. (H.) tricosa,* and *A. abrupta* the anterior outer lip profile is evenly convex rather than scalloped as in species of the *A. falciformis* group.

Anchura pacifica Olsson, 1944, from the Maastrichtian "*Baculites* Zone" of Peru (Olsson, 1944) has similar distant, nearly straight axial ribs and cords on its spire, but on the body whorl *A. halberdopsis* has a more strongly noded periphery and fewer spiral cords on the base.

Type specimens.—Holotype LACMIP 11305, paratypes LACMIP 11306–11311 from CIT locality 1053

Type locality.—CIT locality 1053, northeast-southwest trending spur north of Santiago Creek, 200'N, 2850'E of SW corner sec. 20, T5N, R7W, El Toro quadrangle, Santa Ana Mountains, Orange County, California. Ladd Formation, upper part of Holz Shale Member.

Measured specimens.—See Table 2.

Age.—Early Campanian, Turritella chicoensis holzana Zone; associated with *Submortoniceras chicoense* (Trask) at UCLA locality 4192.

Geographic distribution.—Santa Ana Mountains, Orange County, California in the upper part of the Holz Shale Member of the Ladd Formation [CIT 1053, (20 specimens); UCLA 4192 (2 specimens)], where it is locally common.

Etymology.—English, halberd, a shafted weapon with an ax-like cutting blade + Greek, *opsis,* having the aspect of.

ANCHURA CALLOSA Whiteaves, 1903
Figure 3.5–3.19

Anchura stenoptera Goldfuss. Whiteaves, 1879, p. 123, pl. 15, figs. 11–11a. Not *Rostellaria stenoptera* Goldfuss, 1844.

Anchura callosa Whiteaves, 1903, p. 358 (nom. nov. for *A. stenoptera* Goldfuss of Whiteaves).

Anchura falciformis (Gabb). Taff, Hanna, and Cross, 1940, p. 1327, pl. 2, figs. 7–9. Not *Anchura falciformis* (Gabb, 1864).

Diagnosis.—An Anchura with 12–14 slightly curved axial ribs per whorl; whorl profile rounded on spire with greatest curvature slightly below mid point, angulate on body whorl.

Description.—Shell large, high-spired, drawn out anteriorly into a moderately long anterior rostrum; pleural angle about 22 degrees; whorls about ten in number, nearly evenly convex with greatest curvature slightly below mid whorl; last whorl strongly carinate; suture appressed; growth line antispirally concave on spire; protoconch possibly of about three whorls, not obviously set off from teleoconch. Juvenile sculpture of fine, curved axial ribs; mature sculpture of both axial ribs and spiral cords; axial ribs slightly curved concavely to the aperture, distant, 12–14 on penultimate whorl, slightly nodose where crossed by cords, nodes strongest on angulation of ultimate whorl; eight to ten cords on spire, slight angulation on fifth or sixth cord, forming noded keel on ultimate whorl, base of whorl with two strong cords and four to five weaker cords. Outer lip expanded into falcate wing with shank of moderate length and longer posterior arm; keel of body whorl extends onto wing near posterior margin of wing; wing somewhat expanded with anterior edge rounded at posteriorward bend, thickened along posterior margin, interior channeled opposite keel; distal margin bent adaperturally; posterior arm inclined abaperturally at angle of about 10 degrees to coiling axis. Aperture with broad posterior sulcus and broad anterior sulcus delineated posteriorly by parietal callus pad. Inner lip forming a broad, thin wash to whorl angulation and onto whorl face, developing an elongate, thick callus pad at two strong subperipheral spiral cords. Callus wash continuing around base and onto base of rostrum.

Remarks.—Chico Creek specimens of *Anchura* occurring between about 549 m and 915 m above the base of the Chico Formation constitute a species differing from *A. falciformis* in having a narrower pleural angle, a more rounded profile to the spire whorls, weaker spiral ornament, usually lower axial ribs, sculpture on the abapertural side of the body whorl that is not effaced, producing a more angulate body whorl. Specimens are most distinct from *A. falciformis* low in the Tenmile Member of the Chico Formation but become more similar upsection. Specimens are abundant at UCLA locality 3637 (approx. 625 m above the base) but are difficult to extract from the matrix,

TABLE 3—Measurements in mm of *Anchura callosa* Whiteaves. For abbreviations and symbols used, see introduction.

Specimen	H	Hp	Db	Dp	Dp/Hp	R	PA	S	Ct	Cp	A	Remarks
GSC 5790	56.6	8.4	16.7	13.0	1.55	—	23°	—	8	4	14	body + 7 whorls
CASG 28738.21	47.3	8.6	20.5	14.3	1.66	16.6	—	18.1	7	3	—	body + 1 whorl
CASG 27838.22	36.5	8.1	—	14.1	—	—	21°	—	8	4	14	7 spire whorls
CASG 27838.23	25.6	6.1	—	10.1	—	—	21°	—	8	4	12	6 spire whorls
LACMIP 11312	58.3	9.4	18.4	13.7	1.46	—	20°	—	8	4	15	body + 10 whorls
LACMIP 11313	22.8	4.0	—	6.7	—	—	20°	—	9	4	10	10 spire whorls
LACMIP 11314	48.5	7.7	17.0	12.5	1.62	15.1	—	—	8	4	—	body + 2 + rostrum
LACMIP 11315	38.6	7.5	14.6	—	—	—	23°	—	—	—	—	body + 5 whorls
LACMIP 11316	50.0	10.0	18.5	15.6	1.56	—	22°	12.0	8	4	14●	body + 4 whorls
LACMIP 11317	26.6	7.0	—	11.5	1.64	—	20°	—	11	6	12	5 spire whorls
LACMIP 11318	32.7	5.4	10.8	8.9	1.65	—	21°	—	7	4	12	juv. 8 whorls
LACMIP 11319	30.0	4.7	9.8	7.8	1.66	—	20°	—				juv. 11 whorls
LACMIP 11320	18.3	3.4	7.0	5.8	1.70	—	23°	—	7	4	14	juv. 8 whorls
LACMIP 11344	53.4	8.5	19.5	14.5	1.71	—	21°	—	8	5	15	body + 4 whorls

and no complete specimen has been recovered from that locality. Most specimens from this horizon have a narrower pleural angle and fewer axial ribs than do specimens farther up section, such as those from UCLA locality 3643. The specimen figured by Whiteaves (1879) as *A. stenoptera* from 2.25 miles up the Nanaimo River, Vancouver Island, British Columbia, resembles specimens from about 885 m above the base. That specimen, therefore, appears to fall within the range of the Chico Creek species but is not representative of its most distinctive form. In 1903, Whiteaves decided that he had been mistaken in identifying his Vancouver Island specimen with a species from Westphalia and provided the new name *Anchura callosa* for it. Accordingly, *A. callosa* is taken as the appropriate name for the Chico Creek species.

At the same time that Whiteaves (1903) provided a name, he reported the locality as "Trent River" without indicating that this was a rectification of his earlier locality description. Bolton (1965, p. 7) gave the locality as 2.5 miles up the Nanaimo River, also without indication that this was a correction for Whiteaves' published locality data. According to Muller and Jeletzky (1970, p. 32), Whiteaves' original locality "2 ¼ miles up the Nanaimo River" is within the Cedar District Formation and is the type locality of *Inoceramus vancouverensis* Shumard, 1859, which ranges through the *Submortoniceras chicoense* and *Hoplitoplacenticeras vancouverense* Zones (Ward, 1978, p. 416). A precise locality on the Trent River is not specified, but beds of the Pender Formation that have yielded *Submortoniceras chicoense* are present along the lower Trent River, Vancouver Island. (Haggart and Ward, 1989). The type locality of *Forsia popenoei* Saul, 1988, was inferred to be 2.5 miles up the Nanaimo River. This species occurs with *A. falciformis* and comes from a younger horizon than does *A. callosa* along Chico Creek, Butte County, California. Perhaps future collecting in the Nanaimo basin will elucidate which of the indicated localities would be the most probable provenance for the holotype of *A. callosa.*

Although Whiteaves' illustration strongly resembles *Anchura falciformis,* he did not mention *A. falciformis* and instead (Whiteaves, 1903) compared *A. callosa* to *Anchura transversa* Gabb (1869). *"Anchura" transversa* is based on a specimen 10 mm high and 12.4 mm in diameter including the wing (Stewart, 1927). Its horizon is uncertain, and it does not appear to belong in *Anchura.*

Specimen GSC 5790 appears to be somewhat worn, and the sculpture is subdued. The shell breakage on the body whorl of Whiteaves' (1879, plate 15, figure 11a) drawing corresponds with that of this specimen, but less outer lip is present and more of the spire is missing than in the illustration. The specimen has either been additionally broken since the drawing was made, or the original was in part a reconstruction.

The last whorl of the protoconch is present on LACMIP 11319 but its surface is too poorly preserved to determine whether or not sculpture was present. The fifth? whorl, the first juvenile whorl, has faint remnants of fine, arched axial ribs. Two or three whorls display these arched ribs, which are approximately twice as numerous per whorl as the axial ribs on the adolescent whorls. The change from juvenile to adolescent sculpture is abrupt.

Anchura callosa differs from *A. phaba, A. gibbera,* and *A. baptos* in having stronger and fewer axial ribs, as well as more numerous and relatively weaker spiral cords. *Anchura callosa* further differs from *A. phaba* and *A. gibbera* in having a less protuberant callus pad.

Type specimens.—Holotype GSC 5790 (Bolton, 1965, p. 7). Hypotypes LACMIP 11312–11313 from UCLA locality 3635; LACMIP 11314–11317 from UCLA locality 3637, LACMIP 11318–11320 from UCLA locality 3643; CASG 27838.21 (ex 5794) (figured by Taff et al., 1940, plate 2, figure 9), CASG 27838.22 (ex 5794A) (Taff et al., 1940, plate 2, figure 7), CASG 27838.23 (ex 5794B) (Taff et al., 1940, plate 2, figure 8) from CASG locality 27838, Chico Creek, Butte County, California.

Type locality.—2.25 miles up the Nanaimo River, Vancouver Island, British Columbia (Whiteaves, 1979, p. 123); Trent River (Whiteaves, 1903, p. 359; 2.5 miles up the Nanaimo River. Vancouver Island, British Columbia (Bolton, 1965, p. 7).

Measured specimens.—See Table 3.

Age.—Santonian(?) to early middle Campanian, *Submortoniceras chicoense* Zone, *Turritella chicoensis holzana* Zone. This species is present in the lower part of the Tenmile Member of the Chico Formation on Chico Creek, throughout the zone of reversed magnetic polarity chron 33r and into the beginning of the succeeding normal polarity zone (from UCLA locs. 3632 to 3643).

Geographic distribution.—Cedar District Formation, Nanaimo Basin, Vancouver Island, British Columbia; lower part of the Tenmile Member of the Chico Formation on Chico Creek [from UCLA localities 3632 to 3643], lower beds near Pentz [UCLA locality 4340], Butte County, Tenmile Member of the Chico Formation on Deer Creek [LACMIP localities 15790 and 15792], and Mill Creek [UCLA localities 4662 and 4664], Tehama County, California.

ANCHURA FALCIFORMIS (Gabb,1864)
Figure 4.1–4.12

Aporrhais falciformis Gabb, 1864, p. 127, pl. 20, fig. 83.
Anchura falciformis Gabb, 1864. Gabb, 1868, p. 145, pl. 14, fig. 14;

Gabb, 1869, p. 165; Grabau and Shimer, 1909, p. 755, fig. 1099; Stewart, 1927, p. 360, pl. 22, fig. 9; Shimer and Shrock, 1944, p. 497, pl. 203, fig. 26; Anderson, 1958, p. 165 (in part); Elder and Saul, 1993, pl. 3, fig. 4.

Diagnosis.—An *Anchura* with about 14 straight to slightly curved axial ribs per whorl; carina and axial ribs suppressed abaperturally on body whorl; whorl profile subangulate on spire with greatest curvature about at anterior third of whorl, angulate on body whorl.

Description.—Shell large, high-spired, drawn out anteriorly into a moderately long anterior rostrum; rostrum deflected abaperturally; pleural angle about 25 degrees; whorls about nine in number, unevenly convex, strongly carinate on last whorl; suture appressed. Protoconch apparently smooth, of four whorls, rapidly expanding. Three juvenile whorls scarcely expanding, with fine, curved axial ribs and very fine spiral cords, approximately twice as many ribs per whorl as on mature whorls. Adolescent whorls expanding as in adult, two whorls with coarser axial ribs and stronger spiral cords; next whorl with 12–14 axial ribs, medially angled giving appearance of a medial row of nodes; growth line antispirally concave on spire. Mature sculpture of both axial ribs and spiral cords; axial ribs straight to curved concavely toward the aperture, distant, about 14 on penultimate whorl, forming nodes where crossed by cords, nodes strongest on angulation; seven to eight cords on spire, fifth being strongest, forming bluntly noded keel on ultimate whorl, base of whorl with two strong cords and four to five weaker cords. Outer lip expanded into falcate wing with broad shank of moderate length and longer posterior arm; fifth spiral cord extended onto wing as keel near thickened posterior margin; anterior margin of wing expanded, slightly sinuous, and rounded anteriorly at posteriorward bend; wing interior channeled opposite keel; distal margin bent adaperturally; posterior arm inclined abaperturally at about 10 degrees to axis of spire. Aperture with broad posterior sulcus and broad anterior sulcus delineated posteriorly by parietal callus pad. Inner lip forming a broad, thin wash to whorl angulation and onto whorl face, developing an elongate, thick callus pad at two strong subperipheral spiral cords. Callus wash continued around base and onto base of rostrum.

Remarks.—Gabb's (1864) original figure of *A. falciformis* differs from topotype specimens in having the pleural angle 20 degrees, rather than about 26 degrees, lacking a carina on the last whorl, having a secondary spur on the shank, and in having a more sharply angled wing. However, Stewart (1927) considered this figure to be a synthetigraph, and the lectotype that he designated corresponds well to worn topotype specimens. Well-preserved topotypes commonly have finely beaded cords adapical to the carina. No specimen of *A. falciformis* has been found to have a secondary spur on the shank.

The protoconch of *A. falciformis* described above is from a specimen (LACMIP 11326) from the Cedar District Formation on Sucia Island (UCLA locality 4878). UCLA 11323 has a rostrum 29.5 mm long and UCLA 11324 has a rostrum 29.3 mm long; both are from Butte Creek and in both the rostrum is about one-third of the height of the shell.

The whorl profile of *A. falciformis* is less angulate than that of *A. phaba* or *A. gibbera,* and *A. falciformis* has fewer axial ribs than *A. phaba.* Spiral cords of *A. falciformis* are more numerous than in *A. baptos* and the latter two species. The carina and axial ribs of *A. falciformis* are commonly suppressed on the abapertural side of the body whorl. Although the parietal callus pad is variable in size and shape, the callus pad of *A. falciformis* is usually less elongate and thicker than that of *A. callosa* but less protuberant than those of *A. baptos* and *A. gibbera. Anchura falciformis* lacks the anteriorly directed prong at the bend in the wing that is present in *A. abrupta* and *A. gibbera. Anchura falciformis* has a narrower pleural angle than does *A. abrupta,* and a rostrum deflected backward rather than to the left. The wing of *Anchura falciformis* is more similar to that of *A. haydeni* White, 1879, from the Pierre Shale of Colorado, than to the wing of *A. abrupta.*

Anderson (1958, p. 41) reported *A. falciformis* from CASG locality 28323 on Del Puerto Creek, Stanislaus County, California, in the Panoche Formation, but that specimen is too poorly preserved to be identified to genus.

Type specimens.—Lectotype ANSP 4269; hypotypes LACMIP 12127, 11322–11324 from UCLA locality 6044, Butte Creek, LACMIP 11321 from UCLA locality 3648, Chico Creek, Butte County, LACMIP 11325 from CIT locality 1018, Pentz, Butte County, California, LACMIP 11326 from UCLA locality 4878, Sucia Island, San Juan County, UWBM 16734 from UWBM locality A9254, Sucia Island, San Juan County, Washington.

Type locality.—Chico Creek, Butte County, California

Measured specimens.—See Table 4.

Age.—Middle Campanian, late *Submortoniceras chicoense* Zone to *Hoplitoplacenticeras vancouverense* Zone; *Turritella chicoensis* Zone.

Geographic distribution.—Cedar District Formation, Sucia Island, San Juan County, Washington; Chico Formation, upper part of Tenmile Member, Chico Creek, Butte Creek, higher beds near Pentz, Butte County, and Tuscan Springs (UCLA locality 4082), Tehama County, California.

ANCHURA PHABA new species
Figure 5.1–5.13

Anchura aff. *A. falciformis* (Gabb, 1864). Elder and Saul, 1993, p. 184, pl. 2, figs. 3, 4. Not *Anchura falciformis* (Gabb, 1864).

Diagnosis.—An *Anchura* with about 20 arching axial ribs per whorl forming noticeable nodes on prominent keel (=4th or 5th spiral cord); axial ribs weaker than spiral cords; whorl profile subangulate, angulation at anterior one-third of whorl.

Description.—Shell large, high-spired, drawn out anteriorly into an anterior rostrum; pleural angle about 27 degrees; whorls about nine in number, slightly angulate at fourth spiral cord on spire, strongly carinate on last whorl; suture appressed; protoconch unknown; growth line antispirally concave on spire. Sculpture of both axial ribs and spiral cords; axial ribs curved concavely to the aperture, distant, about 20 on penultimate whorl, forming nodes where crossed by cords; cords dominant, especially on more mature whorls, six to seven cords on spire; cords noticeably noded, especially on penultimate and ultimate whorls; nodes strongest on angulation at fourth cord; base of whorl with two strong and at least two weaker cords; falcate wing with shank relatively short and broad; fourth spiral cord extended onto wing as keel near posterior margin; wing expanded anteriorly an unknown length at posteriorward bend. Anterior margin slightly sinuous. Rostrum nearly straight.

Remarks.—Although more than 30 specimens are identified as *A. phaba,* all are fragmental, and most are poorly preserved. No juvenile specimens without some exfoliation of the shell are known. In all available specimens of *A. phaba,* the anterior rostrum is broken; the longest preserved is that of LACMIP 11333, which is 14.6 mm long and nearly straight. The falcate wing is also incomplete; specimen USNM 468578 shows the shank and the posteriorward bend, but lacks the tip of the anterior extension and part of the posterior arm. That specimen suggests that the shank was relatively wide and short, and that