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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 *Tesarolax* 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. ainikta* 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,

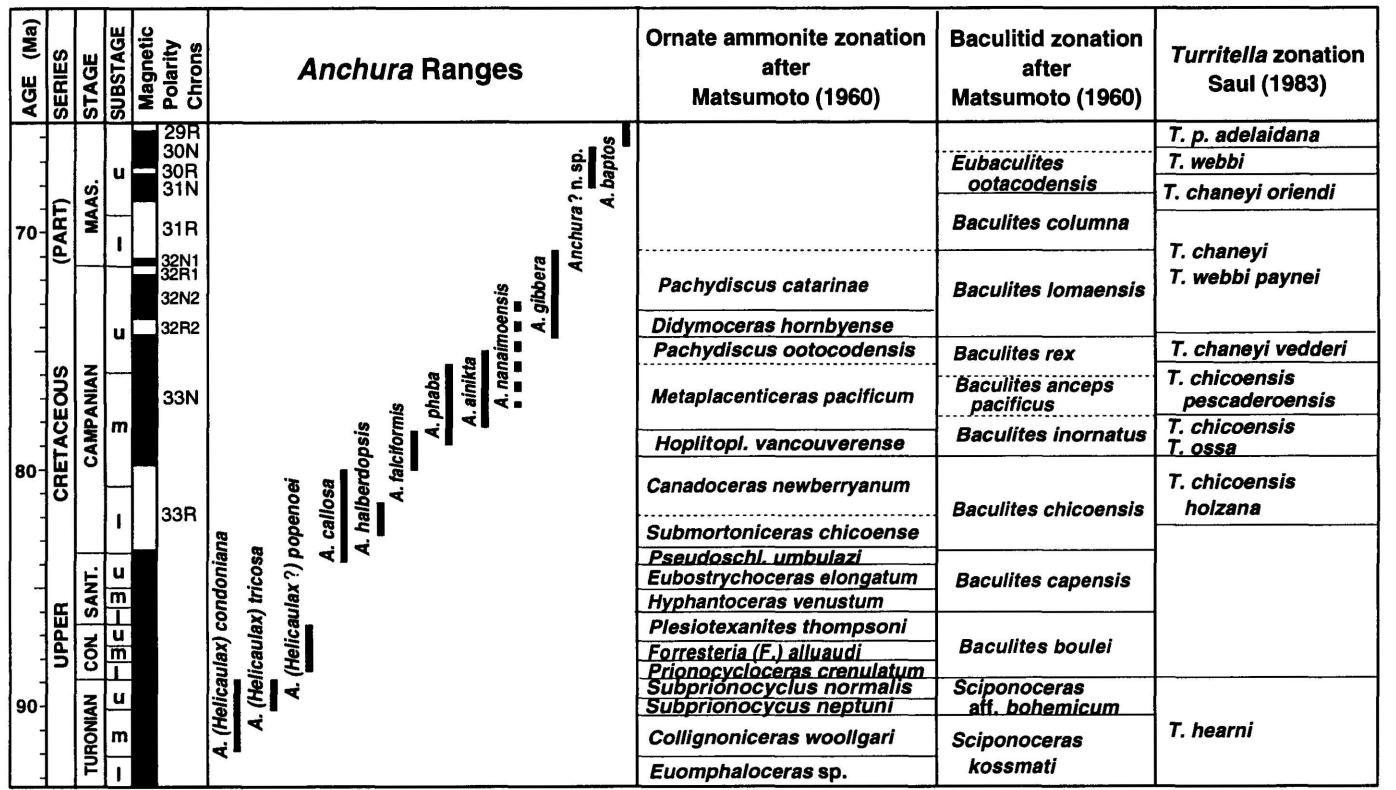


FIGURE 1—*Anchura* ranges plotted against time, rock-stratigraphic units, magnetostriatigraphy, and Pacific Slope ammonite and *Turritella* zones. Ages of stage boundaries based on Obradovich (1993). Magnetic polarity chronology based on Veresub et al. (1989) and Bannon et al. (1989) for ties to Pacific Slope biostratigraphy and Gradstein et al. (1994) for ties to geochronology and chronostratigraphy. Ammonite genera abbreviations are *Hoplitolpl.* 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 aporhaid 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. ainkta*, 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 Paleontología 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 APORRHAIIDAE Gray, 1850
Genus ANCHURA Conrad, 1860

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

Diagnosis. — Medium- to large-sized aporrhaid with high,

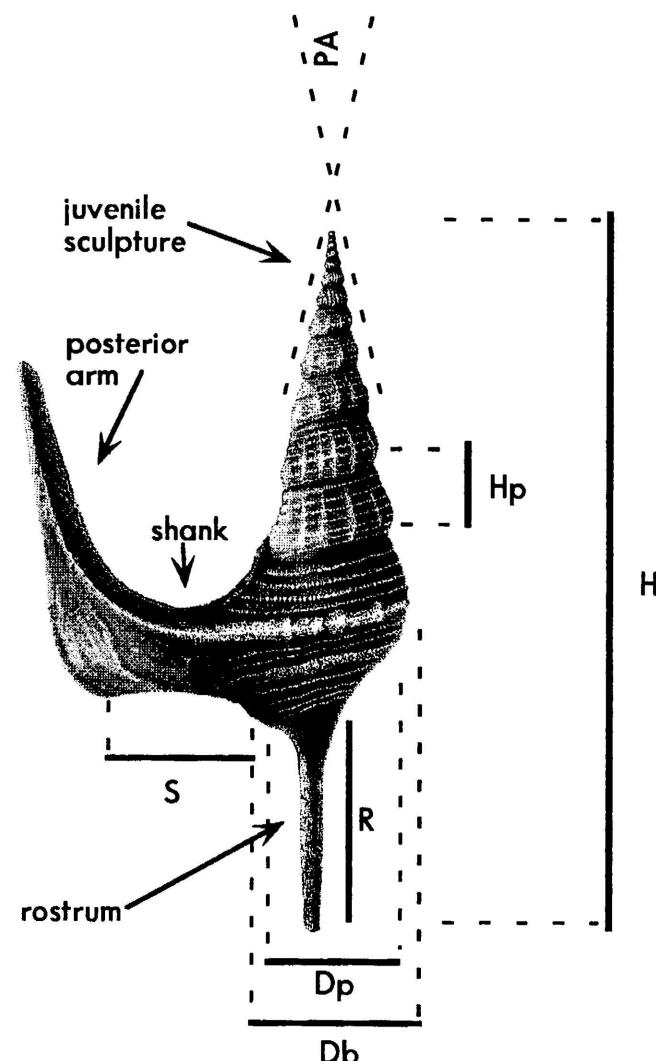


FIGURE 2—Morphology of *Anchura* and diagram of features measured.

evenly tapering spires; sculpture ornate, with both axial and spiral elements, commonly noded at intersections; aperture sub-lenticular; anterior rostrum long and narrow; outer lip elongate, extended into a falcate wing, bent posteriorly.

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. chapellensis* 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-