A new genus of Cretaceous margaritine gastropod (Turbinidae) from the northeastern Pacific Ocean

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ABSTRACT

Igonoia, a new genus of a margaritine vetigastropod, is recognized from Lower and Upper Cretaceous rocks in the northeastern Pacific, in the region extending from Vancouver Island, British Columbia, to southern California. Eight species are known, five are new: the early late Albian I. kieli new species and I. shastana new species; the late Cenomanian I. onoensis new species and I. stewarti (Murphy and Rodda, 1960) new combination; the late Turonian I. vacca new species; the Santonian I. occidentalis (Whiteaves, 1903) new combination; and the Maastrichtian I. angulata (Gabb, 1869) new combination and I. muiri new species. Igonoia is presently known to be endemic to the study area. Specimens are found predominantly in northern California, in fine-grained siliciclastic sandstones that were deposited in warm-temperate, shallow-marine waters. Specimens are most numerous in Santonian rocks.

Additional keywords: Mollusca, Margaritinae, fossil, endemic, temperate waters

INTRODUCTION

Small trochiform vetigastropods present in Cretaceous shallow-marine rocks of the northeastern Pacific are poorly documented in the literature. In the author’s ongoing process of attempting to establish which genera are present, a new genus of margaritine vetigastropod was detected in museum collections. The new genus Igonoia occurs in both Lower and Upper Cretaceous shallow-marine rocks in the region extending from Vancouver Island, British Columbia, Canada to southern California. Specimens are locally abundant but are otherwise uncommon faunal elements. There are eight known species of the new genus, and five of them are new. The three previously named ones were originally assigned to other similar-looking genera. In addition to erecting the new genus, the main purposes of this paper are to describe its species and to record their biostratigraphic succession. The areas where the specimens were collected are shown on Figure 1, and their designations (e.g., Area 3) are used throughout the paper. The details of the type localities of the species are given in the Appendix. The temporal distributions of the species are shown in Figure 2. Paleogeographic and paleoclimatic conditions of the new genus are discussed.

Included in this paper are supplementary descriptions (based on new examination of type material) and refined biostratigraphic records of the three previously named species: Igonoia angulata (Gabb, 1869); Igonoia occidentalis (Whiteaves, 1903); and I. stewarti (Murphy and Rodda, 1960). New information about the type locality of I. angulata is provided, and its type material consists of two species: I. angulata and I. muiri new species. The first photographic views of the type material of I. occidentalis are provided. Additional photographic views of I. stewarti are given, and its type material consists of two species: I. stewarti and I. onoensis new species.

This study was based on 260 specimens borrowed from museums having extensive collections of northeast Pacific Cretaceous fossils. Most of the specimens are stored in the Invertebrate Paleontology Collection at the Natural History Museum of Los Angeles County. The base and umbilical areas of the specimens are commonly encased in well-cemented, fine-grained siliciclastic sandstone. In order to remove this material, it was necessary to use a high-speed drill and diamond-coated grinding wheels, followed by the careful use of hand-held, very sharp needles. Preservation of shell material is generally good. Protoconch and early teleoconch whorls are very rarely present, and mostly or completely decollated. The one moderately well preserved protoconch with its shell intact was sputter-coated...
prior to being imaged by means of an Hitachi S-3000N SEM (scanning electron microscope).

Abbreviations used for catalog and locality numbers are: ANSP: Academy of Natural Sciences, Philadelphia; GSC: Geological Survey of Canada, Ottawa; LACMIP: Natural History Museum of Los Angeles County, Invertebrate Paleontology; UCLA: University of California, Los Angeles (collections now housed at LACMIP); USGS: United States Geological Survey, Menlo Park, California (collections now housed at University of California, Berkeley, Museum of Paleontology).

SYSTEMATIC PALEONTOLOGY

Clade Vetigastropoda Salvini-Plawen, 1980
Family Turbinidae Rafinesque, 1815
Subfamily Margaritinae Stoliczka, 1868

Remarks: This subfamily was previously generally believed to be a trochid subfamily (e.g., Fretter and Graham, 1977; Hickman and McLean, 1990), but, based on molecular studies of extant taxa by Williams et al. (2008), it has been recently and provisionally recognized to be a turbinid. Williams et al. (2009) demonstrated that Margaritinae is not monophyletic.

Genus *Igonoia* new genus

**Type Species:** *Igonoia onoensis* new species, late Cenomanian, northern California.

**Description:** Shell size very small to medium small (4.5 to 13 mm height). Shell height commonly slightly less or approximately same size as shell diameter, rarely greater than diameter. Trochiform. Phaneromphalous. Spire low to moderately high, 43% to 59% of shell height. Pleural angle 80° to 95°. Protoconch smooth (most likely less than one whorl), transition to teleoconch unclear. First teleoconch whorl showing spiral threads before showing any axial ribs. Teleoconch four to six convex whorls; base usually rounded. Suture sunken and commonly groove-like. Teleoconch ornament of spiral ribs (beaded or unbeaded), commonly crossed by raised growth lines, especially on ramp/shoulder areas; shells can be nearly smooth. Shoulder rounded. Aperture circular. Peristome discontinuous. Last whorl large, base convex or keeled. Umbilicus open and deep, bounded by beaded weak to moderately strong spiral rib; umbilical wall can have cancellate ornament where growth lines intersect spiral ribs.

**Geologic Age:** Early late Albian to “mid” Maastrichtian (early late to late middle).

**Etymology:** Named for the adjacent towns of Igo and Ono in the Bald Hills area, Shasta County, northern California.

**Remarks:** After careful examination of each specimen, only two were found with remnants of their protoconch.
present. Only one of these, a specimen of *I. onoensis* 
(Figures 21–22), has the shell intact on its protoconch, 
whereas the other, a specimen of *I. shastana* (Figure 14), 
is missing its shell on the protoconch and adjacent early 
teleoconch whorls (only an internal mold is present).

Gabb (1869) originally assigned the material that 
is now known to comprise *I. angulata* (Gabb, 1869) 
and *I. muiri* new species to genus *Margaritella* Meek 
and Hayden, 1860, a nomen dubium (not *Margaritella* 
Thiele, 1891).

The other previously named species of *Igonoia* were 
assigned eventually by other workers (Whiteaves, 1903; 
Stewart, 1927; Murphy and Rodda, 1960) to the 
solarielline genus *Solariella* Wood, 1842. This is not 
surprising, given that Hickman and McLean (1990) 
reported that solariellines are known to have produced 
covergences with margaritine shells. Fossil species of 
*Solariella* have been characterized (e.g., Davies, 1971; 
Kiel and Bandel, 2001) as having a continuous peri-
stome, spiral cords that can be strongly noded, a keel on 
the base of the shell, and a very prominent spiral cord on 
the rim of the umbilicus. *Igonoia* differs from *Solariella* 
by having a discontinuous peristome, sunken suture, 
shoulder with raised growth lines with or without axially 
aligned beads, whorl sides with or without axially aligned 
beads, and commonly an absence of a very prominent 
spiral rib bordering the umbilicus.

*Igonoia* is similar to genus *Margarites* J. E. Gray, 1847 
(ex Leach ms), but *Igonoia* differs by having a ramp or 
shoulder with raised growth lines with or without axially 
aligned beads, whorl sides with or without axially beads, 
and commonly a less prominent spiral rib bordering the 
umbilicus.

**Igonoia kieli** new species

(Figures 3–8)

**Diagnosis:** Small-sized *Igonoia*, ramp slightly con-
cave, moderately wide, and bearing up to three beaded 
spiral ribs (posteriormost ones more prominent); whorl 
sides smooth or with some prominent growth lines pre-
sent and extending posteriorward across ramp.

**Description:** Shell size small (up to height 8 mm, 
diameter 9 mm, same specimen). Shell height

Figures 3–16. Albian species of *Igonoia* new genus. Specimens coated with ammonium chloride. 3–8. *Igonoia kieli* new species. 3–7. Holotype LACMIP 13682, LACMIP loc. 22900, height 8.7 mm, diameter 9.4 mm. 8. Paratype LACMIP 13683, LACMIP loc. 22900, height 6.6 mm, diameter 8.4 mm. 9–16. *Igonoia shastana* new species. 9, 11, 13, 14, 15. Holotype LACMIP 13684, LACMIP loc. 28757, height 6.3 mm, diameter 6.2 mm. 10, 12, 16. Paratype LACMIP 13685, LACMIP loc. 24369, height 7.5 mm, diameter 8.1 mm.

Holotype: LACMIP 13682, height 8.7 mm, diameter 9.4 mm.

Paratype: LACMIP 13683, LACMIP loc. 22900.

Type Locality: LACMIP 22900, Bald Hills, Ono area, Shasta County, northern California (Area 3).

Geologic Age: Early late Albian (upper Oxytropidoceras packardi ammonite zone).

Distribution: Budden Canyon Formation, Chickabally Mudstone Member, Bald Hills, vicinity of Ono, Shasta County, northern California (Area 3); reworked Albain fossils in lower Turonian Venado Sandstone just south of Sites, Colusa County, northern California (Area 5).

Etymology: Named for Steffen Kiel who has made significant contributions to the study of Cretaceous vetigastropods.

Remarks: The examined material consisted of six specimens: five from loc. 22900 (type locality) and one from loc. 24369. Preservation is generally good. Igonoia kieli co-occurs with I. shastana new species at locs. 22900 and 24369. Locality 22900 is from the upper part of the Chickabally Mudstone Member, and Murphy (1956: figs. 3–5) plotted this locality (as loc. 2900) on his columnar section and on his geologic maps. On his figure 6, he plotted this locality near the top of the Oxytropidoceras packardi ammonite zone, and on the biostratigraphic chart shown by Murphy et al. (1969: fig. 2), it appears that this part of the zone is early late Albian in age.

The single specimen of I. kieli from loc. 24369 is from the Venado Sandstone. This member is of early Turonian age and contains reworked Albain fossils (Squires and Saul, 2004).

Igonoia kieli differs from I. shastana by slightly larger size, subsutural rib, much less uniform ornament, and obsolete ornament on the sides of the whorls. Igonoia kieli is similar to I. muiri new species, but I. kieli differs by having larger size, subsutural rib much weaker on spire whors, absence of flat ramp, less angulate shoulder, more spiral ribs on shoulder, and much less prominent growth lines incising the spiral ribs on the shoulder.

Igonoia shastana new species
(Figures 9–16)

Diagnosis: Small-sized Igonoia, spiral ribs numerous and uniformly noded except on anterior half of last whorl and on posterior part of base of last whorl.

Description: Shell size small (up to height 7 mm, diameter 5.5 mm, same specimen). Shell height approximately 92% of shell diameter. Trochiform. Phaneromphalous. Spire moderately elevated, approximately 50% of shell height. Pleural angle approximately 84°. Protoconch most likely less than one whorl. Teleoconch approximately 4.5 whorls. Suture impressed. All whors with rounded sides. Ornament obsolete on two earliest whorls. Ornament on remaining whors consisting of many closely spaced spiral ribs, beaded except on anterior half of last whorl and on posterior part of base of last whorl. Base demarcated by low angulation. Spiral ribs on base anteriorward becoming wider and bearing beads that become elongate near umbilical rim. Aperture circular. Outer and inner lips thin. Peristome probably discontinuous. Umbilicus wide, its rim angulate and demarcated by spiral rib wider and more strongly beaded than adjacent spiral ribs on base. Umbilical wall cancellate. Area abaxial to umbilical rim with irregularly spaced incised growth lines. Growth lines proloculine, tilted approximately 35° from vertical.

Holotype: LACMIP 13684, height 6.3 mm, diameter 6.2 mm.

Paratype: LACMIP 13685, LACMIP loc. 24369.

Type Locality: LACMIP 28757, Thompson Canyon, Yolo County, northern California (Area 6).

Geologic Age: Early late Albian (upper Oxytropidoceras packardi ammonite zone).

Distribution: Budden Canyon Formation, upper Chickabally Mudstone Member, Bald Hills, Ono area, Shasta County, northern California (Area 3); reworked Albain fossils in upper Cenomanian “Antelope” shale (upper part), just south of Sites, Colusa County, northern California (Area 5); and reworked Albain fossils in Turonian Venado Sandstone, Thompson Canyon, north
of Putah Creek, Monticello Dam area, Yolo County, northern California (Area 6).

**Etymology:** Named for its occurrence in Shasta County, northern California.

**Remarks:** The examined material consisted of eight specimens: three from USGS loc. M-177 (see Squires and Saul [2004: 500] for locality details); two from LACMIP loc. 22900; two from 24369; and one from 28757 (type locality). Distinction between the protoconch and earliest teleoconch whorl cannot be made because the shell is missing in these areas.

*Igonoia stastana* co-occurs with *I. kielii* new species at locality 22900 in the upper part of the Chickabally Mudstone Member, and both co-occur as reworked Albion material at loc. 24369 in the Venado Sandstone. The USGS loc. M-177 specimens also represent reworked material but are from the upper part of the “Antelope” shale in beds approximately 23 to 30 m below the base of the overlying Venado Sandstone.

According to the LACMIP records, loc. 28757 is in the Yolo Formation. On Matsumoto’s (1960: fig. 9) map, this locality plots near the contact between this formation and the underlying Venado Sandstone. Locality 28757 is most likely located in the Venado Sandstone, thus the specimens are also reworked material.

*Igonoia stastana* and *I. kielii* are somewhat similar in that their early whors are smooth and a portion of their last whorl has either diminished or obsolete ornament. *Igonoia stastana* differs from *I. kielii* by slightly smaller size, absence of a subsutural rib, much more uniform ornament, and ornament on the sides of the whors. No known specimens show intermediate morphology between the two species. Future collecting might reveal such specimens, and, hence, the two species could be shown to be conspecific.

**Igonoia onoensis** new species

(Figures 17–23)


**Diagnosis:** Small-sized *Igonoia*, ramp rounded and covered by four to five spiral ribs bearing prominent beads arranged in rows, whorls sides with weak and unbeaded spiral ribs, and basal ornament strong, including wide umbilical cord.

**Description:** Shell size small (up to height 7 mm, diameter 7 mm, same specimen), glossy surface. Shell height approximately same as shell diameter. Trochiform. Phaneromphalous. Spire moderately elevated, approximately 56% of shell height. Pleural angle 92°. Protoconch smooth (most likely less than one whorl), transition to teleoconch unclear; first half whorl of shell measures 0.38 mm (380 μm) diameter. Teleoconch approximately five whors. Earliest teleoconch whorl with two equal-strength spiral threads (one on shoulder and one just anterior to shoulder) and three to four much weaker spiral threads; after another 180°, weaker spiral ribs disappear but spiral threads (two) on or near shoulder continue and become incipiently beaded. All teleoconch whors with rounded sides. Suture impressed. Ramp rounded, narrow, and covered by four to five equant spiral ribs bearing prominent elongate beads arranged in rows. Ornament on whorl sides consisting of weak (rarely obsolete) unbeaded spiral ribs. Aperture subcircular. Outer and inner lips thin. Peristome probably discontinuous. Base ornamented with several strong, moderately narrow spiral ribs. Umbilicus wide, its rim angulate and demarcated by nodulose wide spiral rib. Area abaxial to unbilical rim with irregularly spaced incised growth lines. Growth lines prosocline, tilted 35° from vertical.

**Holotype:** LACMIP 13686, height 7.2 mm, diameter 7.2 mm.

**Paratype:** LACMIP 13687, LACMIP loc. 23476.

**Type Locality:** LACMIP 23476, Bald Hills, Shasta County, northern California (Area 3).

**Geologic Age:** Late Cenomanian (slightly older than *Igonoia stewarti*).

**Distribution:** Budden Canyon Formation, Bald Hills Member, Bald Hills, Ono area, Shasta County, northern California (Area 3).

**Etymology:** Named for the town of Ono, Shasta County, California.

**Remarks:** Examined material consisted of four specimens (one early? adult and three juveniles), all from LACMIP loc. 23476 in the middle part of the Bald Hills Formation. One of the juveniles has its protoconch intact (Figures 21–22). Murphy and Rodda (1960) did not recognize that the specimens they identified as *S. stewartii* from LACMIP loc. 23476 represent a different species than *S. stewartii*. Although both species occur in the Bald Hills Member, *S. onoensis* is found slightly downsection from *S. stewartii*.

Murphy and Rodda (1960: fig. 2) reported that the aporrhaid gastropod *Arrhages (Latiala) californicus* (Gabb, 1864) occurs at LACMIP loc. 23476. Popenoe (1983) assigned this aporrhaid a Cenomanian? to early Turonian age.

The new species is similar to *Igonoia stewartii* but *I. onoensis* is characterized by having prominently beaded spiral ornament, whereas *I. stewartii* is characterized by having weaker ornament consisting of raised growth lines. In addition, *I. onoensis* differs by having smaller size, more sloped ramp, beaded spiral ribs on the ramp, nearly obsolete spiral ribs on sides of the whors, and slightly stronger ornament on the base.

The new species most resembles *Igonoia mutiri* new species but differs by having a larger size, no subsutural cord, rounded shoulder (rather than angulate), and shoulder demarcated by several equal-strength spiral ribs, rather than by only two spirals, with the posteriormost
the strongest. In addition, on *I. onoensis*, the ornament on the base is not as weak abaxially.

*Igonoia stewarti* (Murphy and Rodda, 1960) new combination

(Figures 24–29)

*Solariella stewarti* Murphy and Rodda, 1960: 839 (in part), pl. 103, figs. 4–5.

**Diagnosis:** Small-sized *Igonoia* with spire low, shoulder rounded with numerous very fine to fine spiral ribs crossed by prominently raised growth lines, basal ornament weak, and umbilical cord moderately strong.

**Description:** Shell size small (up to height 8 mm, diameter 9.2 mm, same specimen), glossy surface. Shell height approximately 89% of shell diameter. Trochiform. Phaneromphalous. Spire low, approximately 45% of shell height. Pleural angle 92°. Protoconch unknown. Teleoconch approximately six whorls, all with rounded sides. Suture nearly canaliculated. Shoulder rounded with three to five spiral ribs (noded), commonly very weak to weak. Spiral ornament elsewhere (on sides of whorls) consisting of numerous and closely spaced, weak to rarely moderately strong spiral riblets with tendency to being faint to obsolete. Shoulder with numerous and closely spaced, weak to moderately strong ribs coincident with

**Holotype:** LACMIP 9821 [= UCLA 28622], height 8 mm, diameter 8.9 mm.

**Paratype:** LACMIP 9822 (unfigured here) [= UCLA 28683], LACMIP loc. 23763.

**Type Locality:** LACMIP 23763, Bald Hills, Shasta County, northern California (Area 3).

**Geologic Age:** Late Cenomanian (slightly younger than *I. onoensis*).

**Distribution:** Budden Canyon Formation, Bald Hills Member, Bald Hills, Ono area, Shasta County, northern California (Area 3).

**Remarks:** The examined material consisted of nine specimens: four from LACMIP loc. 23464, three from LACMIP loc. 23465, and five from LACMIP loc. 23763. Preservation is good. Two of the specimens from LACMIP locality 23465 have stronger spiral ribs than normal for this species, and one of these specimens is illustrated in Figure 26. These variants were not mentioned by Murphy and Rodda (1960).

Murphy and Rodda (1960: 839) believed that *S. stewarti* is represented by some of the type material of *Igonoia angulata*. During this present investigation, this latter material was studied and found to consist of two species: *I. angulata* (Gabb) and *I. muiri* new species. The latter species does resemble *I. muiri* (see *I. muiri* for a comparison).

Murphy and Rodda (1960) did not recognize that the specimens they identified as *Solarisella stewarti* from LACMIP loc. 23476 represent a different species. In this present report, these specimens are identified as *Igonoia onoensis* new species, which is found in the middle part of the Bald Hills Member of the Budden Canyon Formation.

*Igonoia stewarti* is present in the upper half of the Bald Hills Member of the Budden Canyon Formation (Murphy and Rodda, 1960: 839, text-fig. 2). The associated macrofauna, especially the species of the gastropods *Gyrodus greeni* Murphy and Rodda, 1960 and *Gyrodus allisoni* Murphy and Rodda, 1960, are indicative of a late Cenomanian age (Popenoe et al., 1987: fig. 1). Murphy and Rodda (1960: fig. 2) also reported that the ammonite *Desmoceeras* (Pseudoheliogella) cf. *barryae* was found with *S. stewarti* at LACMIP loc. 23464, and Matsumoto (1959: 7) reported that this ammonite “seems to occur in the Cenomanian.” Murphy and Rodda (1960) reported the ammonite *Turritites dilleri* from loc. 23464. Rodda (1959) assigned this ammonite a Cenomanian age. Murphy and Rodda (1960) also reported that *S. stewarti* is also present in the “formation” that overlies the Bald Hills “formation.” Using the revised stratigraphy of Murphy et al. (1969), this overlying “formation” is the Gas Point Member (Cenomanian to Turonian) of the Budden Canyon Formation. The present author, however, was unable to confirm a Gas Point Member occurrence of *I. stewarti*.

**Igonoia vacca new species**

(Figures 30–34)

**Diagnosis:** Small-sized *Igonoia* with spire low and teleoconch bearing widely spaced, narrow spiral ribs crossed by widely spaced and raised growth lines, especially on rounded shoulder.

**Description:** Shell size small (up to height 7 mm, diameter 8 mm, same specimen). Shell height slightly less or approximately same size as shell diameter. Trochiform, Phaneromphalous. Spire low, approximately 46% of shell height. Pleural angle 85°. Protoconch unknown. Teleoconch approximately six convex whors. Suture impressed: sutilar area flatish on penultimate whorl. Teleoconch approximately four convex whors. Shoulder area rounded. Ornament consisting of widely spaced, narrow spiral ribs; spire whors with five riblets; spiral ribs on last whorl somewhat clustered together; two near suture, one on shoulder, four to five on sides of whors, and numerous ones on base. Spiral ribs on base gradually become slightly stronger near umbilical rim where raised growth lines cross spiral ornament. Aperture circular. Outer and inner lips thin. Peristome discontinuous. Umbilicus moderately wide, its rim angulate and demarcated by beaded spiral cord with beads grading into nodes toward anterior end of columella. Umbilical wall cancellate. Growth lines prosocline, tilted 30° from vertical.

**Holotype:** LACMIP 13689, height 5.6 mm, diameter 6.6 mm.

**Type Locality:** LACMIP 25421, east of Redding, Shasta County, northern California (Area 2).

**Geologic Age:** Late Turonian.

**Distribution:** Redding Formation, Melton Sandstone Member, east of Redding, Shasta County, northern California (Area 2); Ladd Formation, Baker Canyon Member, Santa Ana Mountains, Orange County, southern California (Area 8).

**Etymology:** Named for its occurrence in the Cow Creek area east of Redding, Shasta County, northern California; vacca, Latin, meaning cow, used as a noun in apposition.

**Remarks:** The examined material consisted of 17 specimens, and nearly all of them are from the Redding...
Formation. Most of the specimens have good preservation. The new species somewhat resembles *Igonoia shastana* new species, but the former differs by having non-beaded spiral ribs and narrower and much more widely spaced ribs.

*Igonoia occidentalis* (Whiteaves, 1903) new combination

(Figures 35–42)

*Solariella (radiatula ? var.) occidentalis* Whiteaves, 1903: 368–369, pl. 45, figs. 5, 5a.

*Solariella roddai* Sald, 1959.

**Diagnosis:** Moderately small-sized *Igonoia* with shell height greater than shell diameter, commonly with prominent subsutural cord, and raised growth lines stronger than nearly obsolete spiral ribs, except on base, on subsutural spiral cord, and on umbilical rim.

**Description:** Shell size moderately small (up to height 13 mm (estimated), diameter 12 mm, same specimen). Shell height approximately 15% greater than shell diameter. Trochiform. Phaneromphalous. Spire moderately high, approximately 59% of shell height. Pleural angle approximately 81°. Protoconch unknown. Teleoconch approximately five to six whorls, all with rounded sides. Suture impressed, rimmed by prominent, unnoded subsutural cord. Shoulder narrow. Ornament generally weak and crossed by raised growth lines. Upper spire whorls with cancellate ornament. Lower spire whorls with many wide-spaced, flat ribs separated by finely incised lines. Last whorl similar to lower spire whorls, except for base with many weak and closely spaced spiral ribs that become slightly stronger anteriorward. Aperture circular. Outer lip thin, inner lip thicker and projecting slightly out over umbilicus. Peristome discontinuous. Umbilicus moderately wide, its rim angulate and demarcated by spiral rib, weakly beaded with beads.
decreasing in strength anteriorward. Base of last whorl
near umbilical rim and umbilical wall cancellate. Growth
lines prosocline, tilted 30° from vertical.

**Holotype:** GSC 5918, height 4.7 mm, diameter
6.9 mm.

**Paratypes:** GSC 5918a, 5918b, 5919, 5919a, all from
the type locality.

**Type Locality:** Vicinity of Nanaimo, Vancouver
Island, British Columbia (Area 1).

**Geologic Age:** Santonian.

**Distribution:** LOWER SANTONIAN: Haslam For-
mation, Benson Creek and Nanaimo River, both in the
vicinity of Nanaimo, Vancouver Island, British Columbia
(Area 1); Redding Formation, upper Member V, Clover
Creek, east of Redding, Shasta County, northern Califor-
nia (Area 2). UPPER SANTONIAN: Redding Forma-
tion, Member VI, Clover Creek, east of Redding, Shasta
County, northern California (Area 2); tentative occur-
rrence in Chico Formation, top of Musty Buck Member,
Chico Creek, Butte County, northern California (Area 4).

**Remarks:** Examined material consisted of 212 spec-
imens, which represents justs over 80% of the known
studied specimens of *Igonoia*. Preservation is moderately
good. Whiteaves (1903) reported that some of his type
material was collected (by others) from Brennan Creek
in the vicinity of Nanaimo, Vancouver Island. According
to R. Graham (person. commun.), it should read Benson
Creek. *Igonoia occidentalis* is most abundant in lower
Santonian rocks at LACMIP loc. 24246 (Area 2), where
168 specimens have been collected. A few weathered
specimens tentatively identified as this new species are
from the top of the Musty Buck Member in the Chico
Formation, Butte County, northern California.

*Igonoia occidentalis* is similar to *Igonoia angulata* but
differs from the latter by much larger shell size, suture
not canaliculate, presence of subsutural rib, and raised
growth lines extending from suture to suture on spire
whorls and from suture to umbilical rim on last whorl.
*Igonoia occidentalis* resembles the Upper Cretaceous
margarite *Atira ornatissima* (Gabb, 1864) from Califor-
nia but differs from the latter by having shell height
greater than shell diameter, subsutural cord, non-sloping
ramp, more prominent growth lines, inner lip not
projected over edge of umbilicus, and umbilical rim
demarcated by an angulation rather than a prominent
spiral rib.

Stoliczka (1867–1868) reported *Solarinella radiatula*
Forbes, 1846, from southern India at the locale of
Odiyam [= Oodium of old usage], which, according to
Sundaram et al. (2001), is stratigraphically situated in
the upper Albian to Cenomanian Karai Formation.
Although Whiteaves (1903) questionably identified
*L. occidentalis* as *Solarinella (radiatula ? var.) occidentalis*,
this species is here identified as *L. occidentalis* because it
is not Forbes’s species *radiatula*.

**Igonoia angulata** (Gabb, 1869) new combination
(Figures 43–47)

*Margaritella angulata* Gabb, 1869: 172 [in part], pl. 28, figs. 55.
*Solarinella angulata* (Gabb), Stewart, 1927: 317, pl. 24, fig. 17.

**Diagnosis:** Very small-sized *Igonoia* with suture
canaliculate, ornament prominent only on shoulder,
prominently raised growth lines on periphery and on
base of last whorl.

**Description:** Shell size very small (up to height
4.5 mm (estimated), diameter 4.8 mm, same specimen).
Shell height approximately same as shell diameter.
Trochiform, Phaneromphalous. Spire moderately high,
approximately 54% of shell height. Pleural angle 80°.
Protoconch unknown. Teleoconch approximately four
whorls. Suture canaliculate. All whorls with flattish
sides. Shoulder angulate, crossed by many prominently
raised growth lines that become obsolete near middle
portion of whorls. Spiral ornament obsolete on spire
whorls; spiral ornament on last whorl consisting of
many very fine threads starting at middle portion of
whorls and continuing onto base. Base demarcated by
rounded angulation; base covered by many very fine
spiral threads that become microscopically beaded
anteriorward. Aperture elliptical. Outer and inner lips
thin. Peristome probably discontinuous. Umbilicus rim
angulate and demarcated by beaded spiral ribs.
Growth lines prosocline, tilted approximately 33° from
vertical.

**Lectotype:** ANSP 4238 (designated by Stewart (1927)
but missing since 1992 (P. Colloman, person. commun.),
height 4.4 mm, diameter 5 mm.

**Paralectotypes:** ANSP 79512 [ex-ANSP 4238].

**Type Locality:** LACMIP 23312, Franklin County,
near Martinez, Contra Costa County, northern Califor-
nia (Area 7).

**Geologic Age:** “Mid” Maastrichtian (late early to mid-
dle late).

**Distribution:** Panoche Formation, Franklin Canyon,
southwest side of Martinez, Contra Costa County, north-
ern California (Area 7).

**Remarks:** The examined material consisted of two
specimens, both previously part of a supposed group of
six ANSP paralectotypes of *Solarinella angulata*. Five of
these specimens are stored together as ANSP 79512 [ex
4238] and the sixth one is ANSP 79153. Of the five
ANSP 79512 specimens, only two are like the drawing
provided by Gabb (1869) and the photograph provided
by Stewart (1927) of the lectotype of *S. angulata*. Of the
remaining three specimens, two belong to *Igonoia muiri*
new species, and one is an indeterminate species
because it has lost most of its shell. The ANSP 79153
specimen is a badly crushed naticid? gastropod, and the
rock matrix filling its aperture is light in color, soft, and totally unlike the blackish-gray, well-cemented siltstone in the apertures of the two specimens of *I. angulata* and the two specimens of *I. muiri*.

Gabb (1869) reported that the type locality of his *S. angulata* to be “at Martinez.” He did not collect the type specimens; they were sent to him by a collector. The area immediately surrounding this city has stratigraphic units ranging in age from Late Cretaceous to Miocene, and there are several faults (Weaver, 1953). The location of the type locality of *I. angulata*, therefore, has been poorly known; subsequently, the geologic age of this species has been uncertain. Inspection (by the present author) of the rock type associated with the two specimens of *I. angulata* revealed a match with the rock type associated with the gastropod *Atira inornata* (Gabb, 1864), which is also found at LACMIP loc. 23312.

Squires (2010) reported that *A. inornata* is of “mid” Maastrichtian age. According to the LACMIP records, this locality is the same as Gabb’s original “at Martinez” Cretaceous locality. On Dibblee’s (1980) geologic map of the area, this locality plots in the Panoche Formation.

Cossman (1918: 257) based the earliest record of genus *Perianulax* Cossmann, 1888, on “Margaritella” *angulata* Gabb, 1869 from the so-called “Chico Group” at Martinez, California. He assigned these strata to the “Aturian,” which according to Harland et al. (1982: 110), generally refers to the Campanian.

**Igonoia muiri** new species
(Figures 48–51)
*Margaritella angulata* Gabb, 1869: 172 [in part].
*Solarilla angulata* (Gabb). Stewart, 1927: 317 [in part].

**Diagnosis:** Very small-sized *Igonoia* with spire low, beaded subsutural rib, ramp flat, shoulder angulate and bearing two spiral ribs (beaded), subsutural area and ramp incised by prominently raised growth lines, and sides of whorls smooth.

**Description:** Shell size very small (up to height 5 mm (estimated), diameter 7 mm, same specimen). Shell height approximately 90% of shell diameter. Trochiform. Phaneromphalous. Spire low, approximately 43% of shell height. Pleural angle approximately 95°. Protoconch unknown. Teleoconch approximately four whorls. Suture impressed, bordered by prominent subsutural beaded rib. Ramp flat. Spire whorls with sides somewhat rounded; last whorl with sides flattish. Ornament on whorls consisting of beaded subsutural rib, stronger

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Figures 43–51. Maastrichtian species of *Igonoia* new genus. 43–47. *Igonoia angulata* (Gabb, 1869), paralectotype ANSP 79512 [ex 4238], LACMIP loc. 23312, height 4.4 mm, diameter 5 mm. 48–51. *Igonoia muiri* new species, holotype ANSP 81350, LACMIP loc. 23312, height 5.2 mm, diameter 7 mm.
beaded spiral rib on angulate shoulder, and one other spiral rib (weaker) just anterior to shoulder; all three ribs incised by moderately widely spaced prominently raised growth lines that become obsolete on middle portion of sides of whorls. Base demarcated by rounded angulation; several weak spiral threads posterior to angulation. Ornament on base consisting of many spiral ribs becoming stronger and beaded anteriorward; beads crossed by prominent growth lines, thereby producing cancellate ornament. Aperture elliptical. Outer and inner lips by prominent growth lines, thereby producing cancellate ornament on base less well developed, and ornament on base somewhat obsolete near middle portion of sides of whorls.

**Holotype:** ANSP 81350, height 5.2 mm, diameter 7 mm.

**Paratype:** ANSP 81351 (unfigured), from the type locality.

**Type Locality:** LACMIP 23312, Franklin County, near Martinez, Contra Costa County, northern California (Area 7).

**Geologic Age:** “Mid” Maastrichtian (late early to middle late).

**Distribution:** Panoche Formation, Franklin Canyon, southwest side of Martinez, Contra Costa County, northern California (Area 7).

**Etymology:** Named for John Muir, early Californian naturalist and visionary conservationist, whose home is in the immediate vicinity of the type locality of the new species.

**Remarks:** The examined material consisted of two specimens, previously part of a supposed group of six paralecotypes of *Solariella angulata* (see “Remarks” for *I. angulata*).

The new species occurs with *I. angulata* at LACMIP loc. 23312, which occurs in strata of “mid” Maastrichtian age (see “Remarks” for *I. angulata*). The new species differs from *I. angulata* by larger size, wider shell, non-canaliculate suture, subsutural rib, two spiral (beaded) ribs on shoulder, and much stronger spiral ribs on base.

*Igonoia muiri* is most similar to *I. onoensis* new species but differs from the latter by having smaller size, subsutural cord, angulate shoulder (rather than rounded), shoulder demarcated by only two spirals, with the posteriormost the strongest (rather than with approximately seven spirals, all nearly equal in strength), ornament on base less well developed, and ornament on base somewhat obsolete near middle portion of sides of whorls.

**PALEOGEOGRAPHIC AND PALEOCLIMATIC COMMENTS**

*Igonoia kieli* and *I. shastana*, the earliest known representatives of this new genus, existed in the Albain, which, according to Hallam (1992: fig. 4.8) and Frakes (1999), was a time of warming ocean waters and a pronounced sea-level rise. During the Albain and Cenomanian, *Igonoia* reached its peak diversity (two species during each stage) in northern California. There was exceptional warming during the Turonian, as well as one of the highest sea-level stands of the entire Cretaceous (Haq et al., 1987; Frakes, 1999). These conditions would have been ideal for *I. vacca* to become widespread in the study area, but the number of specimens is low. In addition to being found in northern California (i.e., approximately 42° N) (Area 2), *I. vacca* also ranged as far south as the Santa Ana Mountains in southern California (Area 8). Based on an analysis of paleomagnetic studies (Dickerson and Butler, 1998: fig. 1), the Santa Ana Mountains are part of a microplate tectonic terrane that would have been even slightly farther south (approximately 32° N, compared to its present-day location at 33° N). Based on volutodermine and opine bivalve studies (Saul and Squires, 2008; Squires and Saul, 2009), warm-temperate surface waters were the norm for the study area and the approximate position of the Late Cretaceous subtropical/warm-temperate boundary shifted from 43° N in the Turonian to 36° N in the Campanian and Maastrichtian.

During the latest Turonian to Coniacian there was marked cooling (Frakes, 1999) and a drastic drop in sea level (Hallam, 1992). No Campanian specimens of *Igonoia* are known. Relative to the Coniacian, there was some warming during the Santonian and early part of the Campanian (Frakes, 1999), and sea level remained generally high (Hallam, 1992). The time of greatest abundance of *Igonoia* specimens was the Santonian, with most of the specimens found in northern California. The occurrence of *I. occidentalis* in the Nanaimo Group on Vancouver Island, British Columbia (Area 1) is an artifact of tectonic transport. Work on Cretaceous molusks by Squires and Saul (2006: 86) and Saul and Squires (2008: 214) supported the contention that the Nanaimo Group was deposited not any farther south than northern California.

No Coniacian age specimens of *Igonoia* are known, and the only study area specimens of *Igonoia* Maastrichtian age are two specimens each of *I. angulata* and *I. muiri*.

In summary, the localities of *Igonoia* are mainly clustered around the 40° N latitude in northern California (Figure 1), thus they plot within the warm-temperate water regime (see Saul and Squires, 2006: fig. 3). Prior to tectonic transport complications, study area *Igonoia* were most widespread, but few in number, during the relatively warm time of the Turonian when temperate waters expanded latitudinally. The highest abundance of specimens, however, was during the Santonian,
which was a cooler time relative to the Turonian. The lack of Campanian-age *Igonoia* and the paucity of Maastrichtian-age specimens are very puzzling, and the reasons await further study.

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APPENDIX 1. TYPE LOCALITIES OF THE NEW SPECIES

Localities are LACMIP. All quadrangle maps listed below are U. S. Geological Survey maps.
Detailed information about the other cited localities in the text is available via the following: LACMIP website: <http://ip.nhm.org/ipdatabase/locality_show>; UCMP website: <http://ucmpdb.Berkeley.edu/loc.html>.

22893. Dark brown sandstone, 5260 ft. S 28.5° W of intersection of Ono-Igo Road and Cottonwood-Igo Road, on East Fork of Hulen Creek, Ono Quadrangle (15 minute), Bald Hills, Ono area, Shasta County, California. Budden Canyon Formation, Huling Sandstone Member. Age: Late Aptian. Collector: M. A. Murphy, January 1, 1951.
22900. 1500 ft. N18°W of confluence of North Fork of Cottonwood Creek and Huling Creek; on Huling Creek, in conglomeratic sandstone forming the narrows; is first sandstone below junction with east fork of Huling Creek, NE/4 of sec. 17, T. 30N, R. 6W, Ono Quadrangle (15-minute, 1952), Bald Hills area, Shasta County, California. Budden Canyon Formation, Chickabally Mudstone Member. Age: Early late Albian (upper part of Oxytropidoceras packardi ammonite zone). Collector: M. A. Murphy, January, 1953.
23312. Crest of 500 ft. ridge on N side of Franklin County, due W of the old John Muir place at S end of city of Martinez, northeastern corner of Briones Valley Quadrangle (7.5 minute, 1959), Contra Costa County, California (= Gabb’s original Martinez Cretaceous locality). Great Valley Sequence. Age: “Mid” Maastrichtian (late early to middle late). Collector: W. P. Popeneo, August, 1944.
25421. Sandstone nodules in shale, left bank of Little Cow Creek, about 5 ft. above the channel bottom, 75 m NE (upstream) from intersection of the creek bed with the line fence, S line of sec. 9, T. 32 N, R. 3 W, Millville Quadrangle (15-minute, 1953), Shasta County, California. Formation: Redding Formation, Melton Sandstone Member. Age: Late Turonian. Collector: W. P. Popeneo, summer 1937.
28757. 2700 ft. N of Putah Creek, section 20, T. 8 N, R. 2 W, Thompson Canyon, just NE of Monticello Dam (forming Lake Berryessa), near the letter “y” in the word “Canyon,” Monticello Dam Quadrangle (7.5 minute, 1959), Yolo County, Venado Sandstone (containing reworked Albian fossils). Age: Turonian (see Matsumoto, 1960: 35).