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Additions and Refinements to Aptian to Santonian (Cretaceous) *Turritella* (Mollusca: Gastropoda) from the Pacific Slope of North America

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Abstract. This paper presents the first detailed paleontologic study of pre-Campanian (pre-late Late Cretaceous) *Turritella* sensu lato from the Pacific slope of North America, mainly from outcrops in California. Seven species, two of which are new, have a cumulative chronologic range of late Aptian to Santonian, an interval of 30 million years that coincides with much of Chron C34, the long-normal interval. One of the new species, *Turritella* ***xylina***, is only the second known Cenomanian *Turritella* from the study area, and the other new species, *Turritella* ***encina***, is the first Santonian *Turritella* reported from the study area. The previously named species are redescribed and are refined in their stratigraphic distributions. They are: *Turritella seriatimgranulata* Roemer, 1849, of late Aptian age; *Turritella infralineata* Gabb, 1864, of late early Albian age; *Turritella petersoni* Merriam, 1941, Cenomanian to early Turonian age; *Turritella hearni* Merriam, 1941, of Turonian and probably Coniacian age; and *Turritella iota* Popenoe, 1937, of late Turonian age. *Turritella seriatimgranulata* is also known from Albian strata in Sonora, Mexico, New Mexico, and Texas.

INTRODUCTION

The shallow-marine gastropod *Turritella* Lamarck, 1799, is common in the uppermost Cretaceous (Campanian and Maastrichtian) through Pleistocene rock record of the Pacific slope of North America. Stemming from the work by Marwick (1957b), many workers have subdivided *Turritella* into other genera and subgenera, and these subdivisions relied on morphologic characters such as the outer lip trace, ontogeny of the primary spirals, and protoconch. Kaim (2004), however, reported that until a thorough review of this genus is done, shell characters cannot be of use for taxonomic purposes above the species level. Lacking this review of turritellas, we refer these species described in this present paper to *Turritella sensu lato*.

Turritellas have been well studied and used with much success for biostratigraphic zonation of the Campanian through Pleistocene rock record of the study area (e.g., Grant & Gale, 1931; Loel & Corey, 1932; Merriam, 1941; Weaver, 1943; Givens, 1974; Saul, 1983a, b; Squires, 1987), but the pre-Campanian record of *Turritella* has received far less study. Reports of pre-Campanian *Turritella* from this region are based mainly on the works of Gabb (1864), Merriam (1941), and Allison (1955). In the last 50 years, however, knowledge of the Pacific slope of North America Cretaceous stratigraphy has increased significantly, and much more collecting has been done. This present study, which expands on the foundation provided by early workers, is based on collections borrowed from all the major museums having extensive collections of Cretaceous fossils from the Pacific slope of North America. We detected 56 lots: 29 at California Academy of Sciences (CAS), 23 at Los Angeles County Natural History Museum, Invertebrate Paleontology (LACMIP), and 4 at University of California Museum of Paleontology, Berkeley (UCMP). These lots were collected mostly from California, and a few were collected from northern Baja California (Figure 1). We found specimens that yielded new morphologic information, and we more fully establish the geologic ranges and geographic/stratigraphic distributions of the five previously named species. In addition, we detected two new species. This study establishes the late Aptian to Santonian record of *Turritella* from California and the northern part of Baja California, Mexico. This interval of geologic time coincides with Chron C34, the long-normal interval (Figure 2). Hereafter, these *Turritella* will be referred to as the "long normal" turritellas. The significance of this study is that *Turritella* can be used for biostratigraphic purposes in working with pre-Campanian rocks.

The shallow-marine, warm-water aspect of the studied species of *Turritella* is generally analogous to the ecology of Recent *Turritella*. A sampling of the literature shows that most species of Recent *Turritella* prefer shallow-ma-

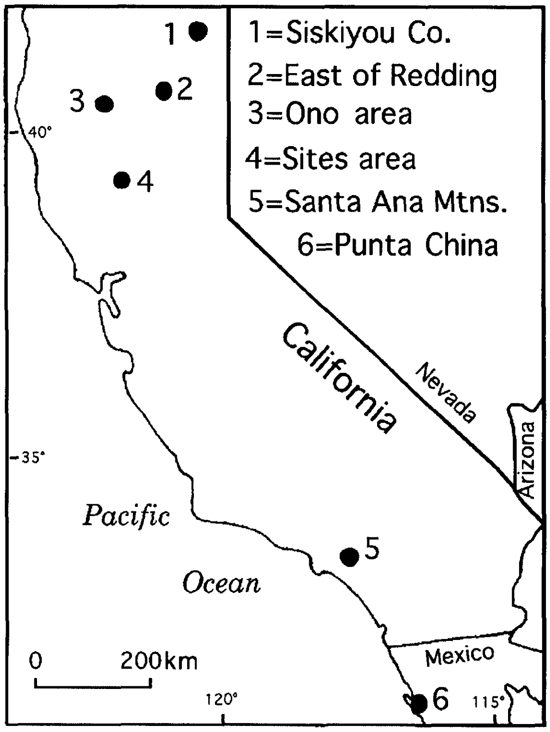


Figure 1. Index map showing locales mentioned in the text.

rine depths between low intertidal and approximately 100 m, even though they have been found in waters as deep as 1500 m (Thorson, 1957; Yonge & Thompson, 1976; Squires, 1984; Saul, 1983a; Allmon, 1988). Recent *Turritella* prefer relatively warm temperatures between 15 and 20°C, although they can live in temperatures between 2 and 24°C (Allmon, 1988). They are, however, specifically more diverse and individually of larger size in the tropics than those found in temperate seas (Merriam, 1941). Most modern-day species are largely sedentary and infaunal/semi-infaunal in relatively soft substrate, but many are also mobile and epifaunal on coarser or harder substrates (Yonge & Thompson, 1976). Some species usually remain immobile for long periods of time, shallowly buried in soft, level-bottom substrates, then voluntarily crawl to more sandy bottoms or bottoms covered with gravel in order to spawn (Bandel, 1976; Yonge & Thompson, 1976; Allmon et al., 1992). Most modern-day species of *Turritella* appear to be ciliary suspension feeders, but some or all might be deposit feeders or grazers at least part of the time (Allmon, 1988; Allmon et al., 1992). They can also be extremely gregarious, with up to approximately 500 individuals per square meter (Merriam, 1941; Petuch, 1976). Information on the mode of development is known (see Marwick, 1957b, Richter & Thorson, 1975, and Bandel et al., 1997) for only a few living species of *Turritella*. Pelagic larval phases are relatively short for these species and range from two days to three weeks (Allmon, 1988).

Figure 3 shows the notational system used here to designate the spiral sculpture. This system, which is based on the work of Marwick (1957a), is explained in the caption for Figure 3.

Abbreviations, other than those cited above, that are used for catalog and locality numbers are: CIT, California Institute of Technology, Pasadena; UCLA, University of California, Los Angeles (collections now housed at LACMIP); USNM, United States National Museum, Washington, D.C.

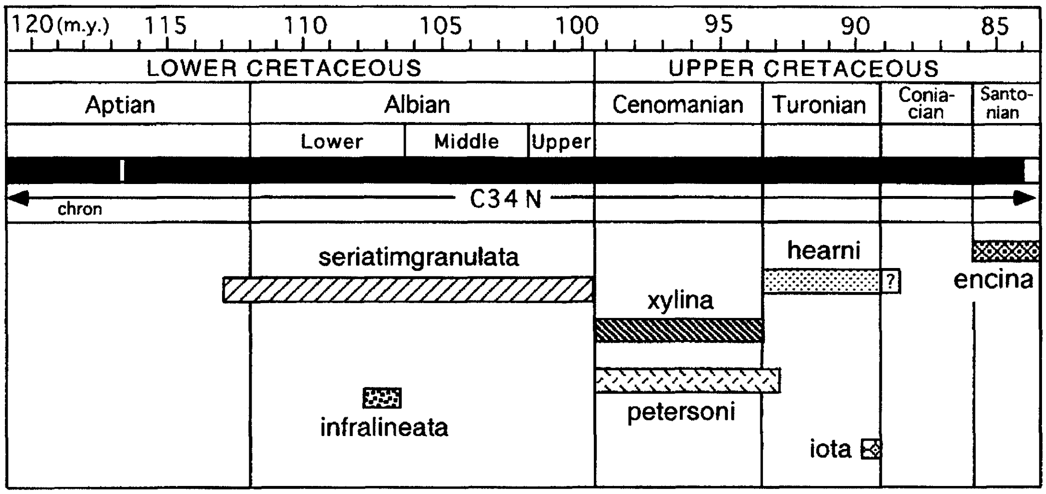


Figure 2. Chronostratigraphic positions of the new and restudied Cretaceous turritellas. Ages of stage boundaries and magnetostratigraphy data from Gradstein et al. (2004:fig. 19.1).

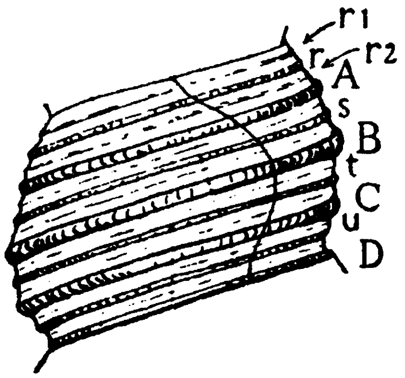


Figure 3. Diagram showing notation of spiral ribs of *Turritella*. Primary ribs are denoted A, B, C, and D; secondary ribs are denoted by r, s, t, and u; and tertiary threads are denoted by r_1, r_2, etc. Change in relative rib strength shown by exchanging upper for lower case letters (i.e., capital letters for strong ribs and lower case for weaker ribs). (Diagram modified from Marwick, 1957a:fig. 1).

STRATIGRAPHY

The geologic ages and depositional environments of most of the Pacific slope of North America formations and members cited in this paper have been summarized in papers by Saul (1982) and Squires & Saul (2003a, b, 2004a, b). These ages range from late Aptian through Santonian, and the depositional environments are usually shallow marine, with post-mortem displacement of some of the shallow-marine faunas into deeper waters via turbidity currents. Stratigraphic information mentioned below concerns those rock units not discussed in recent literature.

Cretaceous Rocks Near Yreka

The holotype of *Turritella hearni* Merriam, 1941, was reported by Merriam (1941:64) as having been collected "... from the Turonian at the type locality near Montague and Yreka ...," both of which are in Siskiyou County, northern California. Montague is approximately 8 km slightly southeast of Yreka. Although Merriam never specifically mentioned whether the type locality is at Montague or Yreka, Anderson (1958:153) reported the locality to be in middle Turonian beds on the Hagerdorn Ranch, 6.4 km north of Montague. Museum labels in the box that contains the holotype have two locations cited: one at 6.4 km north of Montagu and one 13 km northeast of Yreka. The label that has the official CAS locality number (61938) is the former location. Matsumoto (1960:97) indicated the beds 6.4 km north of Montague to be Coniacian in age, based on a few ammonites. Utilizing the outcrop map of Sliter et al. (1984:figs. 1, 2), beds in the area just north of Montague (i.e., the Black Mountain area) plot in the lower Coniacian part of the Hornbrook Formation and are probably part of the Ditch Creek Siltstone Member. Sliter et al. (1984) based their geologic age on the ammonite *Prionocycloceras* sp. These same workers, however, reported that just southwest of the Black Mountain area, there are extensive covered intervals and small discontinuous outcrops of sandstone and siltstone which cannot be correlated to the exact member of the Hornbrook Formation. The age of the beds at the type locality of *T. hearni,* therefore, cannot be positively determined, but the age is probably early Coniacian.

Turritella hearni is also present in the extension of the Hornbrook Formation in Turonian strata (LACMIP loc. 25272) near Phoenix, Jackson County, southwestern Oregon. For a discussion of the age of the strata in this area, see Squires & Saul (2004b).

Lower Part of Tuna Canyon Formation

Turritella iota Popenoe, 1937, is reported here for the first time from the lower part of the Tuna Canyon Formation west of Rustic Canyon in the east-central Santa Monica Mountains, Los Angeles County, southern California. The specimens are from coarse-grained sandstone at LACMIP loc. 26967 in the basal part of the formation. Overlying the basal part is a black-shale unit containing scaphitoid-ammonites (Popenoe, 1973; Almgren, 1973; Colburn, 1973). Alderson (1988), based on ammonites, reported that the black-shale unit is late Turonian to Coniacian age and that the underlying coarse-grained sandstone beds (i.e., those containing *T. iota*) are late Turonian in age and are coeval to the upper Baker Canyon and the lower Holz Shale members of the Ladd Formation in the Santa Ana Mountains, Orange County, southern California. Prior to this present paper, *Turritella iota* had only been found in the lower Holz Shale Member of the Ladd Formation; thus, the presence of *T. iota* in the Santa Monica Mountains strengthens the age equivalency of these parts of these two formations.

BIOGEOGRAPHIC IMPLICATIONS

The earliest known records of *Turritella* are from the Early Cretaceous (early Valanginian) of Poland (Schröder, 1995; Kaim, 2004) and the Valanginian of France (d'Orbigny, 1842). The earliest known record of *Turritella* on the Pacific slope of North America is *Turritella seriatimgranulata* Roemer, 1849. It occurs in the Tethyan gastropod- and bivalve-rich fauna (Allison, 1955, 1974) of the upper Aptian Alisitos Formation, northern Baja California, Mexico, and this species is described and illustrated in this present report. The arrival of *Turritella* onto the Pacific slope of North America during the late Aptian coincided with both a global trend of rising sea level (Haq et al., 1987) and with warm and equable surface waters (Frakes, 1999).

During the Albian through Turonian, warm-water conditions existed on the Pacific slope of North America

(Saul, 1986). Shallow-water Albian strata are not plentiful in the study area, and most of the shallow-water Albian mollusks contained in these strata are from redeposited blocks. During the Albian, *T. seriatimgranulata* migrated into New Mexico, Texas, and Sonora, Mexico. Although surface currents were predominantly westward-flowing during the Aptian and Albian in the southern part of North America, there were substantial eastward-flowing surface currents (see Johnson, 1999:figs. 2, 3) that could have transported the larvae of *T. seriatimgranulata* eastward from the westward part of Mexico.

The Turonian coincided with widespread warm seas that were at their highest sea-level stand of the Cretaceous (Haq et al., 1987; Frakes, 1999), and the Turonian coincided with the peak in diversity for *Turritella* species in the study area, with collectively three species present (Figure 2). Two of these species, *T. petersoni* and *T. hearni,* had the widest geographic distribution of all the studied species.

Relative to the Turonian, the Coniacian to early Campanian had a slightly cooler climate (Frakes, 1999), and only a moderately high sea-level stand (Haq et al., 1987). The boundaries of the Tethyan Realm were generally broadest during the Aptian to Turonian and the narrowest during the Coniacian to Maastrichtian (Sohl, 1987). These more restrictive conditions might help explain why there is only a single known species, *Turritella* ***encina*** sp. nov., of limited geographic distribution, known from the study area during the interval represented by the Coniacian and Santonian. The paucity of exposures of shallow-water Coniacian strata in California accounts for the scarcity of Coniacian turritellas.

Superorder CAENOGASTROPODA Cox, 1959
Order NEOTAENIOGLOSSA Haller, 1882
Family TURRITELLIDAE Lovén, 1847
Genus *Turritella* sensu lato Lamarck, 1799

Type species: *Turbo terebra* Linneaus, 1758, by monotypy; Recent, western Pacific.

Diagnosis: Shell small to large, turreted-conical, many whorled, elongate, slender, sculptured with spiral ribs and/or threads, growth lines curved, aperture round and entire, outer lip thin, sinuous and prosocline at suture, columella smooth and concave, operculum horny and multispiral (after Davies, 1971:309).

Discussion: The growth lines, noded ribs, and early whorl sculpture of six of the seven turritellas treated in this paper (i.e., *T. seriatimgranulata, T. infralineata, T. petersoni, T. hearni, T. iota,* and *T.* ***encina***) are similar. On the basis of shell characteristics, none of these "long normal" turritellas resembles the most common Campanian-Maastrichtian turritella stock of *Turritella chicoensis* Gabb, 1864. Very early whorls of *T. chicoensis* stock appear bicostate (ribs B and C) although the peribasal spiral D is present, and the whorls become quadricostate (A, B, C, D) by the eight whorl. Early whorls of seventh turritella treated in this paper (i.e., *T.* ***xylina***) are unavailable, but adult whorls resemble those of *Turritella chaneyi* Merriam, 1941, stock.

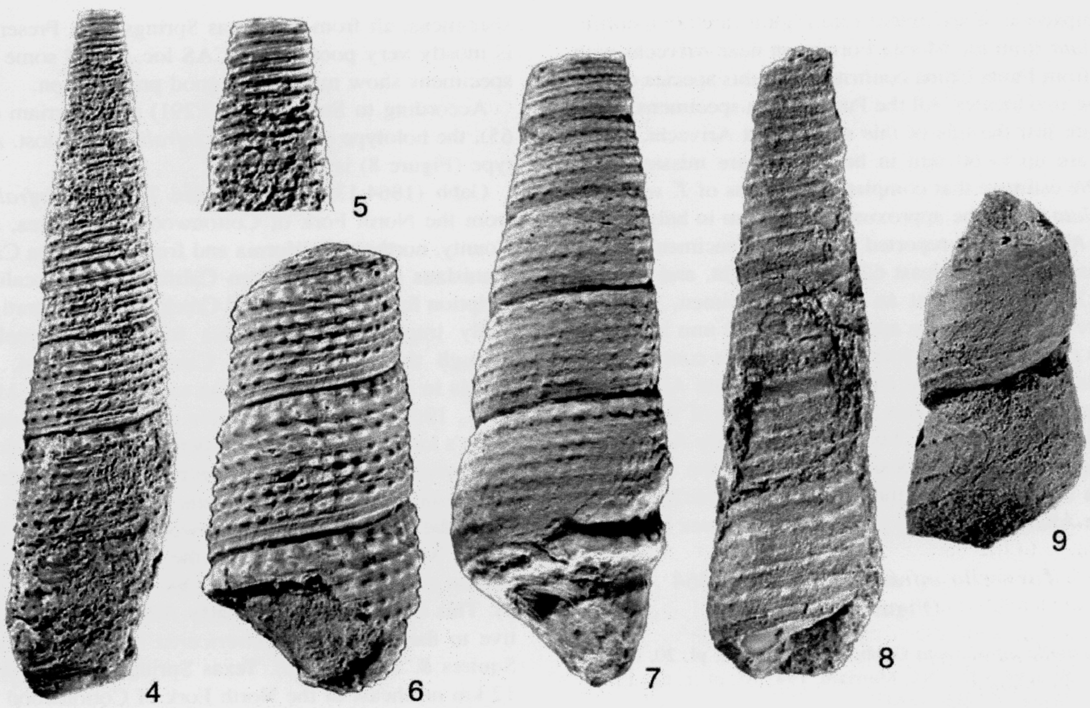
Turritella seriatimgranulata Roemer, 1849
(Figures 4–7)

Turritella seriatim-granulata Roemer, 1849:413; 1852:39, pl. 4, figs. 12a, 12b; Gabb, 1869:263; Stanton, 1947: 75–76, pl. 56, figs. 7, 11, 17–24; Almazan-Vazquez, 1990:159, pl. 1, fig. 8; Akers & Akers, 1997:93, fig. 78.
Not *Turritella seriatim-granulata* Roemer. Gabb, 1864:132, pl. 20, fig. 88 (two views: natural size and magnified) = tentatively, *Turritella packardi* Merriam *fide* Saul (1983a:102–104).
Not *Turritella seriatimgranulata* Roemer. Stewart, 1927: 348–349, pl. 21, fig. 2 = tentatively, *Turritella packardi* Merriam *fide* Saul (1983a:102–104).
Not *Mesalia seriatim-granulata* (Roemer). Shimer & Shrock, 1944:495, pl. 203, figs. 3, 4.
Turritella marnochi White, 1879:314, pl. 7, fig. 5b (not 5a).
Turritella vibrayeana d'Orbigny. Böse, 1910:145, pl. 30, fig. 10; pl. 31, fig. 6.
Turritella macropleura Stainbrook, 1940:712, pl. 33, figs. 17, 20–21.
Mesalia (Mesalia) mauryae Allison, 1955:414–415, pl. 41, fig. 3.
Turritella (Haustator) aff. *T. (H.) seriatimgranulata* Roemer. Allison, 1955:415, pl. 41, fig. 5.

Diagnosis: Adult whorls generally flat sided, with five nearly equal-strength spiral ribs, closely spaced, noded, and alternating with finer noded ribs; R strongest and carina-like. Interspaces with unnoded threads.

Description: Shell medium-large (up to 90 mm, estimated, in height), slender. Pleural angle narrow (15°). Protoconch and earliest juvenile whorls unknown. Teleoconch whorls approximately 15 to 17, flat-sided; posteriormost part of whorls with slightly rounded profile. Late-juvenile whorls (approximately 1.75 mm diameter) with four (R, A, B, and C) nearly equal and squarish ribs, interspaces deep and smooth and about same width as ribs. Adult whorls (approximately 5 mm diameter and greater) with five (R, A, B, C, and D) spiral ribs, nearly equal in strength (R strongest, projecting and somewhat carina-like), equidistant, noded, and alternating with weaker ribs (also noded); resulting in sculpture pattern R, r_2, A, s, B, t, C, u, and D. Rib r_1 occasionally present, approaching R in strength, with nodes on both ribs nearly merging. Nodes variable in strength, weakest on D. Threads on all interspaces, very thin, variable in number (three to six), and unnoded; threads most numerous on interspace between B and C, and C and D. Suture deep. Aperture round, inner lip can have thin callus pad. Base of last whorl with unnoded spiral ribs.

Holotype: USNM 103148.



Explanation of Figures 4 to 9

Figures 4–9. Specimens coated with ammonium chloride. Figures 4–7. *Turritella seriatimgranulata* Roemer, 1849. Figures 4–5. Hypotype UCMP 156008, UCMP loc. A-9521. Figure 4. Abapertural view, ×3.5. Figure 5. Tip of specimen shown in Figure 4, ×8.7. Figure 6. Hypotype UCMP 156009, UCMP loc. A-9521, right-lateral view, ×4. Figure 7. Hypotype UCMP 156010, from near Arivechi, northern Sonora, Mexico, apertural view, ×2.5. Figures 8–9. *Turritella infralineata* Gabb, 1864, CAS loc. 69104. Figure 8. Neotype CAS 69286, apertural view, ×3.4. Figure 9. Hypotype CAS 69287, abapertural view, ×3.1.

Type locality: Either the Walnut Creek or Comanche Peak formation near Fredericksburg, Gillespie County, south-central Texas (Stanton, 1947:76).

Geologic age: Late Aptian to late Albian.

Distribution: UPPER APTIAN: Alisitos Formation, marine part of upper member, Punta China region, northern Baja California, Mexico. APTIAN-ALBIAN UNDIFFERENTIATED: Morita Formation, Cerro las Conchas, near Ariveachi, Sonora, Mexico. UPPER LOWER ALBIAN: Washita and Fredericksburg Groups, Texas. UPPER ALBIAN: Pawpaw Formation, Texas; Purgatorie Formation, Mesa Tucumcari, New Mexico.

Discussion: This study of *T. seriatimgranulata* is based on approximately 1000 specimens from the Alisitos Formation near Punta China (UCMP loc. A-9521) and two specimens from the Morita Formation near Arivechi. The Alisitos material consists entirely of the tips of specimens, and the preservation is very good.

Poorly preserved small fragments of *Turritella* identified as *T. seriatimgranulata* Roemer in Gabb (1864) and Stewart (1927) from Tuscan Springs, Tehama County, northern California were tentatively regarded by Saul (1983a:102–104) to be *Turritella packardi* Merriam, 1941, which is of early to possibly middle Campanian age.

Shrimer & Shrock (1944) refigured both the natural-size view and the magnified view of Gabb's (1864:pl. 20, fig. 88) specimen and identified it as *Mesalia seriatimgranulata.*

Mesalia (*Mesalia*) *mauryae* Allison, 1955, is known only from one locality in the Alisitos Formation. This locality is where *T. seriatimgranulata* is also found. *Mesalia* (*M.*) *mauryae* is known only from tips of specimens, and their sculpture is identical to that of the tips of some specimens (see Figure 5) of *T. seriatimgranulata.* For this reason, we believe *M.* (*M.*) *mauryae* to be a synonym of *T. seriatimgranulata.*

Gabb (1869:263) reported specimens of *T. seriatimgranulata* from the Morita Formation near Arivechi, Sonora, Mexico. Stanton (1947:76, pl. 56, figs. 17, 18, 23, 24) stated that these Mexican specimens appear to be within the form range of *T. seriatimgranulata,* and he provided illustrations of two specimens of Gabb's original lot.

Comparison of specimens (see Figure 7) of *T. seriatimgranulata* from the Morita Formation near Arivechi with those from Punta China confirmed that this species occurs at these two locales. All the Punta China specimens, however, are just the tips of this species. At Arivechi, specimens are up to 60 mm in height and are missing their tips. We estimate that complete specimens of *T. seriatimgranulata* would be approximately 90 mm in height. Akers & Akers (1997) reported that Texas specimens of this species are up to at least 62 mm in height, and Stanton (1947:75) reported that an average specimen, with the apex restored, would be approximately 70 mm in height.

The age range of the formations in Texas containing *T. seriatimgranulata* is late early Albian to late Albian, according to Akers & Akers (1997); the age of the Purgatorie Formation in New Mexico is late early Albian, according to Cobban & Reeside (1952); and the age of the Morita Formation in northern Mexico is undifferentiated Aptian-Albian, according to Almazan-Vazquez (1990).

Turritella infralineata Gabb, 1864
(Figures 8–9)

Turritella infralineata Gabb, 1864:131–132, pl. 20, fig. 87; Stewart, 1927:291; Merriam, 1941:65, pl. 1, fig. 13 (refigure of Gabb, 1864).
Turritella cf. *T. hearni* Merriam. Rodda, 1959:123–124 (unfig.).

Diagnosis: Adult whorls generally flat-sided, with four to five, nearly equal-strength spiral ribs (C strongest and can be slightly carina-like), widely spaced and weakly noded; interspaces bearing numerous threads.

Description: Shell medium, slender. Pleural angle narrow (11°). Protoconch and juvenile whorls unknown. Teleoconch with flat-sided to weakly concave whorls. Early adult whorls (approximately 5 mm diameter) with four (R, A, B, and C) nearly equal ribs, weakly noded, and separated by wide interspaces bearing numerous unnoded threads; C strongest and somewhat carina-like. Adult whorls with five (R, A, B, C, and D) nearly equal ribs, R and C strongest, with C usually somewhat carina-like. Ribs s and u occasionally somewhat prominent on later whorls. Suture impressed. Aperture round. Base of last whorl unknown. Growth line deeply sinused, sigmoidal with antispiral sinus between A and B ribs.

Neotype: CAS 69286 (designated herein).

Neotype locality: CAS loc. 69104.

Geologic age: Late early Albian, *Brewericeras hulenense* ammonite zone.

Distribution: Budden Canyon Formation, Chickabally Mudstone Member, Texas Springs area, Shasta County, northern California.

Discussion: This study of Gabb's species is based on 49 specimens, all from the Texas Springs area. Preservation is mostly very poor, but at CAS loc. 69104 some of the specimens show moderately good preservation.

According to Stewart (1927:291) and Merriam (1941:65), the holotype of *Turritella infralineata* is lost. A neotype (Figure 8) is chosen here.

Gabb (1864:131–132) reported *Turritella infralineata* from the North Fork of Cottonwood Creek area, Shasta County, northern California and from Orestimba Canyon, Stanislaus County, northern California. His locality description for the Cottonwood Creek locality is stratigraphically imprecise because this fork of the creek cuts through the entire Budden Canyon Formation, which ranges in age from Hauterivian to Turonian (see Murphy et al., 1969:pl. 1). The probable stratigraphic position of Gabb's locality, however, was determined during this present investigation, based on specimens matching the original description of *T. infralineata* from the general vicinity of the North Fork of Cottonwood Creek in the Chickabally Mudstone Member of the Budden Canyon Formation at Texas Springs in the Ono area (Figure 1, locale 3). This member is of late early Albian age and correlative to the ammonite *Brewericeras hulenense* zone (see Squires & Saul, 2004b). Texas Springs is approximately 12 km northeast of the North Fork of Cottonwood Creek area. *Turritella infralineata* occurs at several localities in the Texas Springs area, and a total of 16 specimens were detected. The largest specimen is 35 mm in height, but it is incomplete. Preservation is generally poor, but a few good specimens, including the neotype, are from CAS loc. 69104.

We were not able to confirm Gabb's (1864) report of the occurrence of *T. infralineata* from Orestimba Canyon, Stanislaus County, and we were not able to make definite identifications of many of the fossils from this area. The canyon cuts across rocks ranging from Jurassic? and Early Cretaceous to early Tertiary age, and detailed field studies are needed in this area before any definitive biostratigraphic work can be done.

Turritella infralineata resembles *T. hearni,* but *T. infralineata* differs by having much weaker nodes and much wider interspaces.

Turritella ***xylina*** Squires & Saul, sp. nov.
(Figures 10–12)

Turritella cf. *T. robertiana* (Anderson). Rodda, 1959:124; Murphy & Rodda, 1960:text-fig. 2.

Diagnosis: Adult whorls with concave middle part flanked by shoulder and abapical angulations. Sculpture generally subdued, consisting only of numerous spiral threads.

Description: Shell medium (estimated 40 mm total height). Protoconch and early juvenile whorls unknown. Pleural angle 18°. Early adult whorls (approximately 4.5