



## First record of Late Albian canaliculate rudist from northern California and re-assessment of *Durania? californica* Anderson, 1958

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### ABSTRACT

Rudist specimens of Late Albian age from the Upper Chickabally Mudstone Member of the Budden Canyon Formation, Great Valley Sequence, in northern California, are identified as a canaliculate rudist taxon based on shell morphology and mineralogy. Since they are incomplete right valves without cardinal and myophoral parts, their systematic placement is difficult, though their canal characters are similar to those of relatively derived caprinuloidinid rudists such as *Texicaprina* and *Jalpania* (Caprinidae) of the Caribbean/Gulf region. Re-assessment of the holotype specimen of *Durania? californica* from the Upper Albian of northern California reveals that it does not belong to the Radiolitidae, but is also a canaliculate rudist. The distribution of canaliculate rudists, probably caprinuloidinids, in the mid-latitudes of the Northeast Pacific suggest that this area belonged to the Tethyan Realm at that time, and a faunal connection existed between the Northeast Pacific and the Caribbean and/or the Central Pacific at least in the Late Albian.

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### 1. Introduction

The distribution of rudist bivalves (Superfamily Hippuritoidea) is often considered as a good indicator of the tropical marine environment and biotic realm (Tethyan Realm) in the Cretaceous, and has been used for many paleobiogeographic and/or paleoceanographic studies (e.g., Kauffman, 1973; Sohl, 1987; Masse, 1992a; Johnson et al., 1996; Johnson, 1999). In the Pacific Coast region of North America, the presence or absence of rudists has been used to interpret environmental and faunal changes in this area (e.g., Saul, 1986), though rudist records from this region are not common. Late Campanian–Early Maastrichtian *Coralliochama* from Baja California, Mexico and the coastal region of northern California, U.S.A. (White, 1885; Marincovich, 1975; Aranda Manteca, 1991; Johnson and Hayes, 1993; Götz et al., 2005) have attracted attention notably from the viewpoint of evaluating the model of large lateral displacement of the western part of the North American continent (e.g., Kodama and Ward, 2001). Recent reports of *Praebarrettia sparcilirata* and a radiolitid in addition to *Coralliochama* from the Campanian of the Santa Ana Mountains, southern California (Filksorn, 2005), and *Pseudopetalodontia* (Monopleuridae), *Tepeyacia* (Polyconitidae) and several species of

Caprinuloidinae from the Lower Albian of Baja California (Paynes et al., 2004; Masse et al., 2007a) add new information for further studies.

There are also some rudist records from the Cretaceous sequence of the inland part of northern California and southern Oregon, located to the east of the San Andreas Fault. Lupper and Packard (1930) described *Lithocalamus colonicus*, from probable mid-Cretaceous deposits of southern Oregon. Anderson (1958) described *Durania? californica* (Radiolitidae) from northern California and southern Oregon. Although the sequences containing them represent fore-arc basin deposits that accumulated along the western margin of North American craton at that time, and have much potential to contribute to paleogeographic and/or paleobiogeographic discussion, these rudists have received little attention for a long time, because of their rare occurrence and poor preservation in the siliciclastic sequences.

Two canaliculate rudist specimens were newly collected from the Upper Albian of the Great Valley Sequence, northern California. Their systematic placement is discussed in this paper. Furthermore, re-investigation of the holotype specimen of *Durania? californica* reveals that this taxon is also a canaliculate rudist, and does not belong to the Radiolitidae. Thus it is evident that canaliculate rudists expanded their distribution to the mid-latitudes of the Northeast Pacific in the Late Albian. These records contribute further to the paleobiogeographic investigation of the Cretaceous Pacific.

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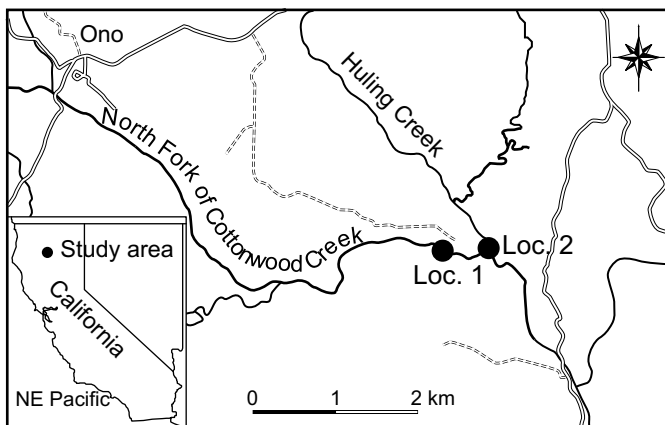
E-mail address: [iba@eps.s.u-tokyo.ac.jp](mailto:iba@eps.s.u-tokyo.ac.jp) (Y. Iba).

**2. Geologic setting**

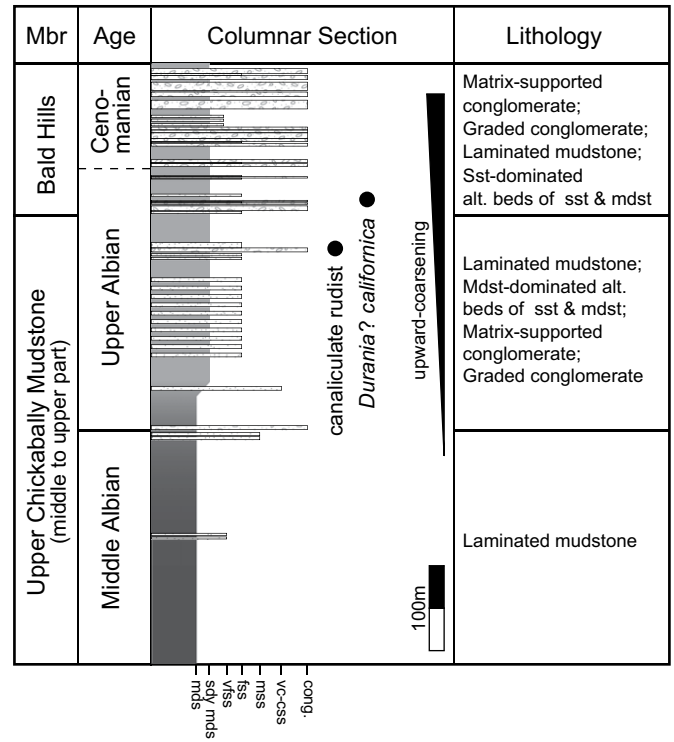
Marine Cretaceous rocks, called the Great Valley Sequence, are well exposed on the surface or underlie younger rocks throughout most of the Ono area, Shasta County (Fig. 1) on the west side of the Sacramento Valley in the foothills of the northern California Coast Ranges. Cretaceous marine rocks in the Ono area, named the Budden Canyon Formation (Murphy et al., 1969), are represented by a thick sequence of fossiliferous clastics, and range in age from Hauterivian? to Turonian. The Budden Canyon Formation includes the most continuous and fossiliferous Lower Cretaceous strata, especially for the Aptian–Albian interval, in the circum-North Pacific region, and has been the object of several biostratigraphic and paleontologic studies (Anderson, 1938; Murphy et al., 1969; Murphy and Rodda, 1996; Amédro and Robaszynski, 2005).

Murphy (1956) and Murphy et al. (1969) subdivided the Budden Canyon Formation into eight members: Recter Conglomerate (Hauterivian?), Ogo (Hauterivian), Roaring River (Barremian), Lower Chickabally Mudstone (Barremian), Huling Sandstone (Upper Aptian), Upper Chickabally Mudstone (Upper Aptian to Upper Albian), Bald Hills (Upper Albian to Cenomanian) and Gas Point members (Cenomanian to Turonian), in ascending order based on characteristic differences in lithology.

Two rudist specimens were newly recovered from the matrix-supported conglomerate of the upper part of Upper Chickabally Mudstone Member, in a section studied along the North Fork of Cottonwood Creek in the Ono area (Loc. 1 of Figs. 1 and 2). Other bivalves such as *Exogyra* and a chondrodontid(?) were found with the rudist specimens. Their occurrence in the matrix-supported conglomerate and also poor preservation of the shells clearly indicates they were probably transported into this area from the nearby shallower shelf. Based on the previous ammonite biostratigraphic studies (Amédro and Robaszynski, 2005), this horizon is assigned to the *Mortoniceras perinflatum* zone (Upper Albian). The specimens are deposited in the California Academy of Sciences (CASG 70794 and 70495). The holotype of *Durania? californica* was collected from near the confluence of Huling Creek and North Fork of Cottonwood Creek (Loc. 2) where the lowest part of the Bald Hills Member (Upper Albian; Murphy and Rodda, 1996; Amédro and Robaszynski, 2005) is exposed (Figs. 1 and 2). This specimen is likewise deposited in the California Academy of Sciences (CASG 1346.02).



**Fig. 1.** Locality map of canaliculate rudist specimens in the Ono area on the west side of the Sacramento Valley, northern California Coast Ranges. Two canaliculate rudist specimens were recovered from Loc. 1 (N 40°27'16.0", W 122°34'05.9") and the holotype of *Durania? californica* from Loc. 2 (N 40°27'14.42", W 122°33'40.36").



**Fig. 2.** Generalized lithological columnar section of the Middle Albian–Cenomanian part of the Budden Canyon Formation in the Ono area showing rudist-bearing horizons. The columnar section is based on the research of the exposure along the North Fork of Cottonwood Creek. Geological age based on Murphy and Rodda (1996) and Amédro and Robaszynski (2005).

**3. Method—Identification of shell mineralogy—**

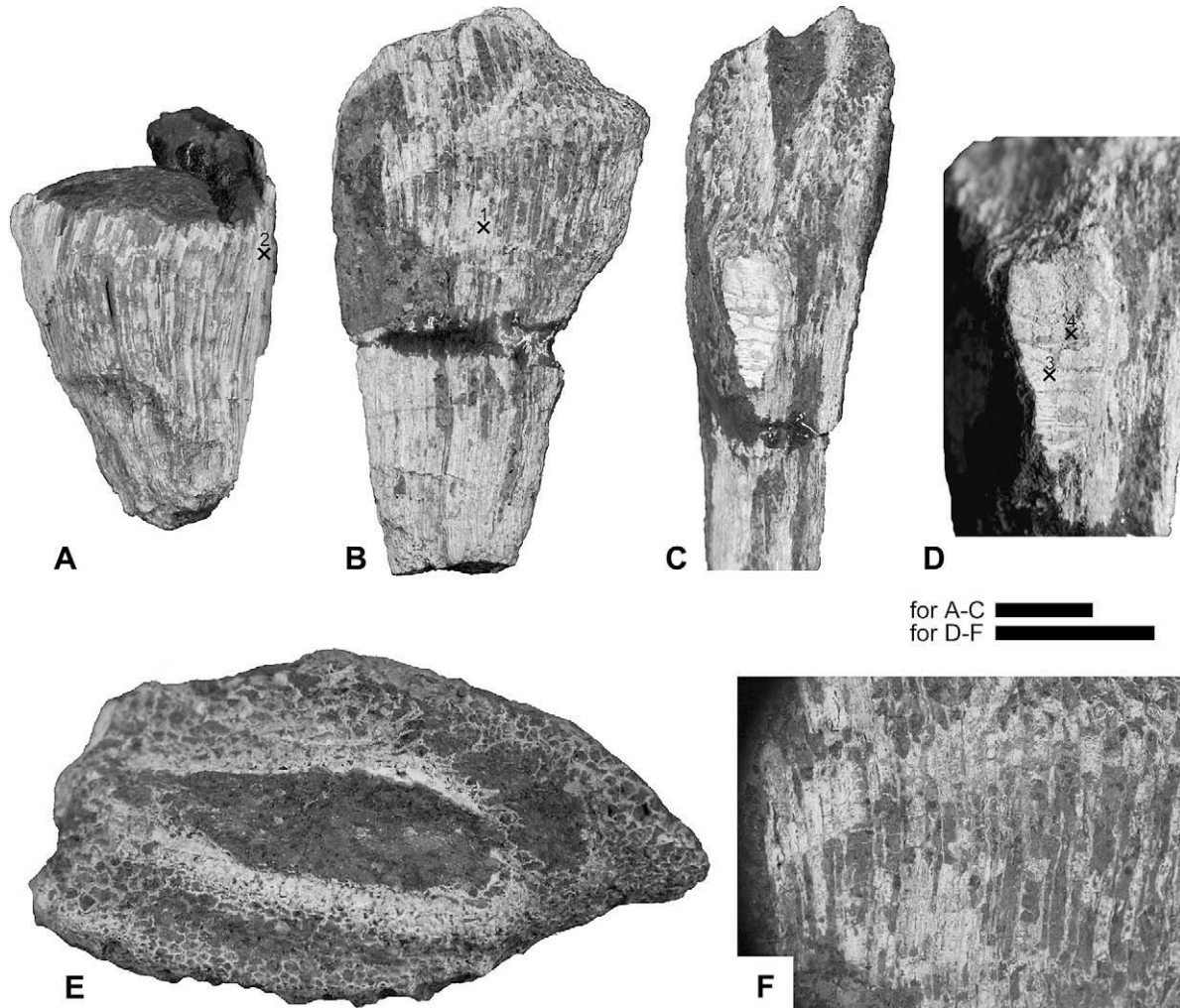
Mesostructures of the shell wall, such as polygonal cells in the outer shell layer of radiolitids and pallial canals in the inner shell of caprinids, are very useful for the identification of rudists (e.g., Dechaseaux et al., 1969; Skelton and Smith, 2000). Since all rudists had an originally aragonitic inner shell and calcitic outer shell layer (Skelton and Smith, 2000), it is possible to distinguish the inner or outer layer of well-preserved rudist specimens based on shell mineralogy. Here we applied Raman spectroscopy to the Californian rudist specimens.

Raman spectroscopy is an ideal method for identifying polymorphs of materials, because it provides excellent fingerprint spectra specific to each crystal structure. A Raman microprobe in the Geochemical laboratory, Graduate School of Science, The University of Tokyo, was used for this study. Raman spectra were obtained on a 30 cm single polychromator (Chromex, 250is), equipped with an optical microscope (Olympus, BX60), Ar+ ion laser (514.5 nm; ion laser technology, 5500 A), and a charge-coupled device (CCD) camera with 1024 × 128 pixels (Andor, DU-401-BR-DD SH). The Rayleigh line was removed using a holographic supernotch filter (Kaiser, HIPF-514.5–1.0). The Raman shift was calibrated with a standard sample of naphthalene. The beam size of the incident laser was approximately 2 mm on the sample surface.

**4. Identification of Californian rudist specimens**

**4.1. Shell morphology**

Both the new specimens from the Upper Chickabally Mudstone Member are incomplete right valves (Figs. 3A, B), and white in color. They were originally conical, but are now slightly deformed and flattened. Shell heights are 65.2 and 44.6 mm, and maximum



**Fig. 3.** Canaliculate rudist specimens from the Ono area. A, CASG 70495. Lateral view showing longitudinal canals. B–F, CASG 70494. B, Lateral view showing longitudinal canals. C, Lateral view showing partly-preserved massive shell component. D, Enlarged view of massive shell component (Fig. 3C). Originally aragonite, but transformed into yellowish calcite in places around cracks. E, Transverse view. Several (possibly up to ten) rows of polygonal canals are observed across the entire shell wall of the specimens. F, Enlarged lateral view. Tabulae are intermittently inserted inside canals. Analysed points using Raman spectroscopy: (1) in Fig. 3B, (2) in Figs 3A, (3) and (4) in Fig. 3D, which correspond to each in Fig. 4, are shown. Scale bars = 1 cm.

widths are 37.4 and 27.3 for CASG 70794 and 70795, respectively. A component of massive shell remains in one part of CASG 70794 (Fig. 3C), though, in most parts, the shell is very porous. The entire thickness of the shell wall is canaliculate in transverse section, and up to about ten canal-widths deep (Fig. 3E). The polygonal cross-sectional shape of the canals is variable because of deformation, and the diameter of each polygon is usually less than 1 mm, but in places reaches 2 mm. Horizontal tabulae are intermittently inserted inside the grooves on the eroded sides of the shells, where the canals are exposed in longitudinal section (Fig. 3F). These tabulae do not continue across neighboring canals, being entirely contained within them. Cardinal and myophoral parts have not been clearly identified.

#### 4.2. Shell mineralogy

Three points in CASG 70794 and a single point in CASG 70795 were analysed using Raman spectroscopy (Figs. 3A, B and D). The partly preserved massive shell component of CASG 70794, which could possibly represent the myostracum of one of the myophores, is originally white in color (Fig. 3D), but changed to yellowish in places around cracks. Both parts were analysed separately. The obtained Raman spectra are shown in Fig. 4: (1) and (2) from the

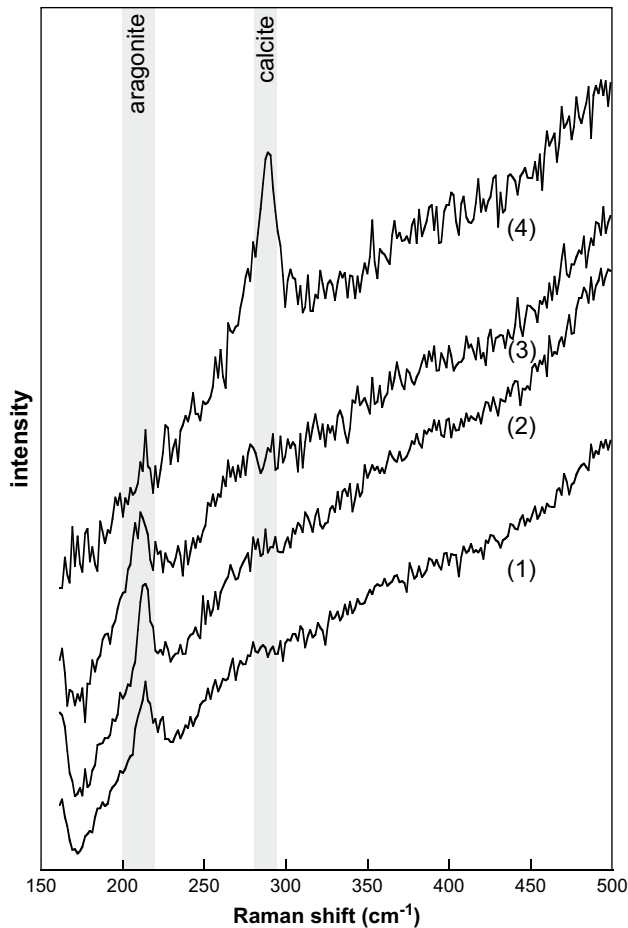
canaliculate parts of CASG 70794 (Fig. 3B) and 70795 (Fig. 3A), respectively; (3) from the white part of massive shell component (Fig. 3D); and (4) from the yellowish part of the latter in CASG 70794 (Fig. 3D).

Calcium carbonate has three polymorphs (calcite, aragonite, and vaterite) and these three polymorphs can be distinguished from one another by observing bands at the lower energy region (e.g., Kontoyannis and Vagenas, 2000). A characteristic narrow peak for calcite is observed at  $281\text{ cm}^{-1}$  and that for aragonite is observed at  $150\text{ cm}^{-1}$  and  $205\text{ cm}^{-1}$ , whereas the vaterite bands are very large and overlap with the above-mentioned peaks of aragonite and calcite (Dandeu et al., 2006). These results (Fig. 4) show that aragonite is preserved in the white part of the shells, and that the yellowish part indicates transformation from original aragonite to calcite. Since the original mineralogy of the canaliculate structure of these specimens is aragonite, it must belong to the inner shell of the rudist, and therefore it cannot be interpreted as radiolitic calcitic celluloprismatic outer shell mesostructure.

#### 4.3. Systematic placement of the Californian canaliculate rudist

The Californian rudist specimens are confidently identified as a canaliculate rudist, based on the presence of canals in their inner





**Fig. 4.** Measured data of Raman spectroscopy on canaliculated rudist specimens: (1) and (2) from porous parts of CASG 70494 and 70495, respectively; (3) from white part of massive shell component of CASG 70494; (4) yellowish part of massive shell component of CASG 70494.

shell. Tabulae are intermittently situated within the canals. Neither a ligament groove nor pyriform canals in the margin can be identified, though their absence could be due to the dorsal and marginal parts of these specimens having been worn away. Multiple (perhaps up to ten) rows of small canals of polygonal cross-section are developed across the entire bounding wall of the likely body cavity of the shell, with the exception of the partly-preserved aragonitic massive (possibly myostracal) shell component. It is thus evident that the canals were not restricted to the marginal part of the shell, but also invaded the inner shell, presumably including the teeth and the walls that separate the body cavity from the tooth sockets and accessory cavities.

Canaliculate rudists were previously all assigned to the Caprinidae in the *Treatise* (Dechaseaux et al., 1969), but such a grouping is now considered polyphyletic (Skelton and Smith, 2000), and canaliculate taxa are classified separately among the Caprinidae (s.s.), the *Neocaprina*–*Caprinula* clade (Steuber and Bachmann, 2002), Plagiptychidae, Dictyptychidae, Ichthyosarcolitidae, Antillocaprinidae and a few among the Radiolitidae (Skelton, 2003). We follow the rudist classification of Skelton (2003) in this study. Two monophyletic families and one also putatively discrete clade of canaliculate rudists, the Caprinidae (s.s.), Ichthyosarcolitidae and the *Neocaprina*–*Caprinula* clade existed in the Aptian–Cenomanian interval, and are candidates for comparison with the Californian canaliculate rudist in this paper.

*Ichthyosarcolites*, the only genus of the Ichthyosarcolitidae, has a distinctively large and usually arcuate to coiled right valve, and

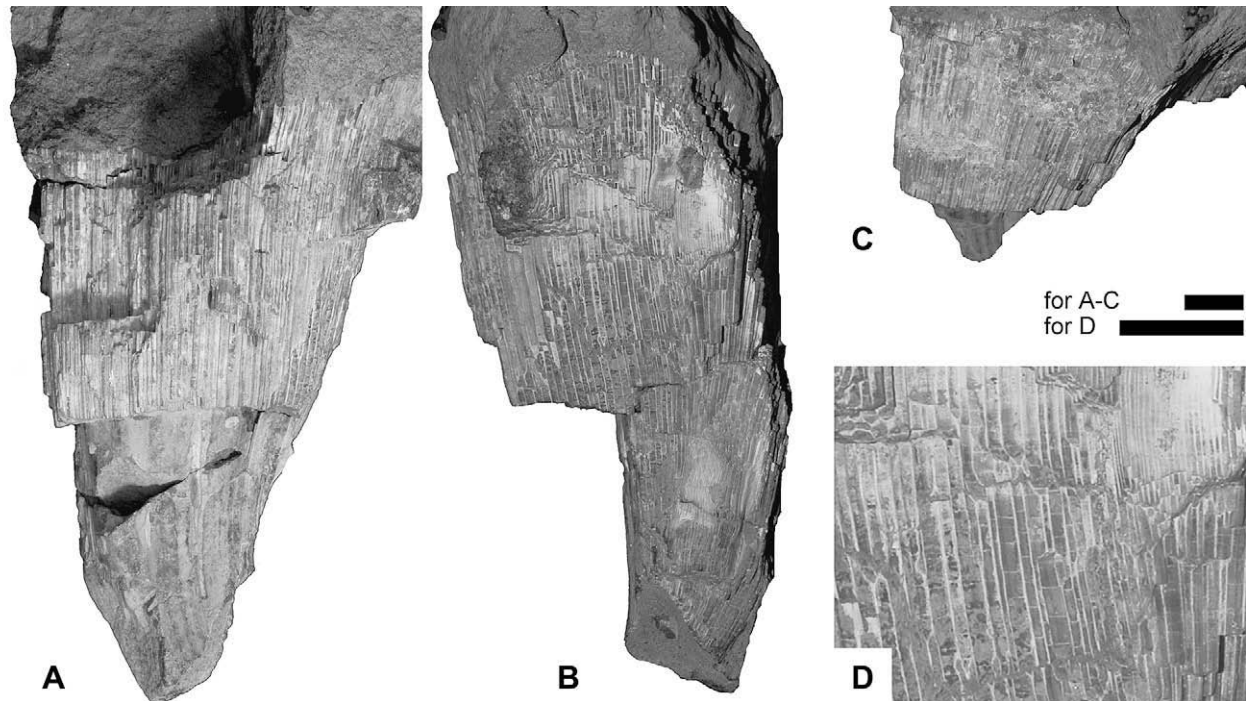
reputedly lacks tabulae in its fine capillary-like canals of sub-polygonal cross-section (Mac Gillavry, 1937; Cestari et al., 1998). Hence the Californian canaliculate rudist appears not to belong to this genus and family.

Canal patterns increase in complexity through time in several lineages, and this trend is frequently used for the identification of genera in the Caprinidae (e.g., Dechaseaux et al., 1969; Coogan, 1973; Chartrousse, 1998; Pantoja-Alor et al., 2004). The Family Caprinidae is divided into the subfamilies Caprinuloidinae, Mac Gillavry, 1970 (=Coalcomaninae Coogan, 1973) and Caprininae, d'Orbigny, 1850 (Skelton and Masse, 1998; Skelton and Smith, 2000). Development of multiple rows of such consistently small, tabulate canals of polygonal cross-section throughout the right valve has not been recognized either in the Caprininae, with the exception of some derived species of *Offneria* restricted to the Lower Aptian of the Old World (Masse, 1992b), or in the *Neocaprina*–*Caprinula* clade, which is again restricted to the Old World. However, such a development is common in advanced forms of the Caprinuloidinae, i.e., taxa more derived than *Coalcomana* and primitive *Caprinuloidea* (Coogan, 1973; Chartrousse, 1998). *Kimbleia* and *Mexicaprina* may develop up to a few rows of polygonal canals inside a marginal row of pyriform canals (Coogan, 1973; Alencáster and Oviedo-García, 1998; Scott, 2002); *Caprinuloidea*, *Guzzyella* and *Muelleriedia* have a compact internal shell wall (Coogan, 1973; Alencáster, 1998). *Jalpania*, known from the Upper Albian of NW Mexico, has similar fine tabulate canals throughout the right valve wall, but also develops a row of tubercles in the anterior side of the left valve, and corresponding pits in the right valve (Alencáster and Aguilar-Pérez, 1996). However, it is not possible to check for this last character in the Californian specimens, given their eroded and crushed condition, so assignment to this genus cannot be rejected. Nevertheless, the above-mentioned characters recognized in the Californian canaliculate rudist are also concordant with those of *Texicaprina*, which is widely recorded from the Middle–Upper Albian of Texas, Mexico, Trinidad, Jamaica, Cuba, and Guatemala (Coogan, 1973; Rojas et al., 1996; Scott, 1996, 2002; Alencáster and Oviedo-García, 1998; Scott and Filkorn, 2007). *Immanitas* also shows canal characters similar to those of *Texicaprina* (Coogan, 1977) and could be another candidate. However, its very large size contrasts markedly with that of these specimens. Aguilar (2006) recently proposed affinity of Albian–Cenomanian *Immanitas* to the Antillocaprinidae, though members of the latter family are otherwise known only from the Santonian–Maastrichtian (Skelton, 2003). However, the myocardial organization of *Immanitas* is typical of caprinuloidinids (Skelton, unpublished data), and it seems more likely that the large infoldings in the anterior shell wall are merely convergent with those seen in more derived antillocaprinids (Mitchell and Gunter, 2006), probably in connection with the adoption of a comparable obligate recumbent life habit. The Late Albian age of the Californian canaliculate rudist is consistent with the stratigraphic range of all of *Texicaprina*, *Jalpania* and *Immanitas*.

In conclusion, definitive generic placement of the Californian canaliculate rudist is difficult at present, though it is most probably a relatively derived caprinuloidinid caprinid such as *Texicaprina*, *Jalpania* or a related form. Detailed studies of additional specimens, which preserve cardinal and myophoral parts, are necessary to resolve its systematic assignment.

#### 4.4. Re-assessment of *Durania? californica* Anderson, 1958

*Durania? californica* was previously the only rudist described from northern California (Anderson, 1958). Investigation of the holotype (CASG 1346.02; Figs. 5A, B) reveals that the putative polygonal celluloprismatic structure (Fig. 5C) in *Durania? californica* in fact consists of pallial canals. Intermittent transverse partitions



**Fig. 5.** Holotype (CASG 1346.02) of *Durania? californica* Anderson, 1958. A, Lateral view. B, Lateral view from the right of Fig. 5A. C, Polygonal structure (canals). D, Enlarged lateral view of the central part of Fig. 5B. Tabulae are intermittently inserted inside canals. Scale bars = 1 cm.

inserted within the canals do not form continuous cell floors ('funnel plates' or 'planchers') as expected in the outer shell layer of radiolitids (cf Skelton and Smith, 2000: fig. 10a), but, instead, represent tabulae, like those seen in the canaliculate rudists described above (Fig. 5D). Hence *Durania? californica* is not a radiolitid, but a canaliculate rudist. A partial section of a paratype specimen (Anderson, 1958, plate 1, figure 2) shows that, in transverse section, a single row of pyriform canals exists at least in parts of the shell margin, and polygonal canals fill most part of the inner shell layer, also indicating that this specimen is not a radiolitid but a canaliculate rudist. Since cardinal and myophoral arrangements cannot be observed in these specimens, it is difficult to assign them to a particular genus. However, based on canal characters, they are similar to the Californian rudist specimens described herein, and are considered possibly to belong to the same taxon. In addition, there are no other confirmed records of *Durania* in the Americas below the Lower Turonian (Cobban et al., 1991; Steuber, 2002), contrasting with the Mediterranean records of this genus starting from the latest Albian (e.g., Masse et al., 2007b).

#### 4.5. Comparison with *Lithocalamus colonicus* Lupper and Packard, 1930

Lupper and Packard (1930) described a gregarious canaliculate rudist, *Lithocalamus colonicus*, from the Cretaceous deposits of southern Oregon, which probably accumulated in a similar fore-arc tectonic setting as the Great Valley Sequence in northern California (Nilsen, 1986). Thus comparison of the Californian rudist with *Lithocalamus* should be mentioned briefly. The size and canal characters of *Lithocalamus* are consistent with those of the Californian rudist. However, the close siting of two nearly equal-sized tooth sockets and tightly clustered growth habit in *Lithocalamus* are not recognized nor indicated in the Californian rudist.

Systematic placement of *Lithocalamus* itself is still controversial. It was originally assigned to the Caprinidae (Lupper and Packard, 1930; Anderson, 1958). Although Mac Gillavry (1937) pointed out

similarities between *Lithocalamus* and *Antillocaprina*, the former genus was later placed in "Family Uncertain" in the *Treatise* (Dechaseaux et al., 1969), and remains unrevised. The taxonomic identity of *Lithocalamus* remains unclear, and requires further study of the original material.

#### 5. Paleogeographic and paleobiogeographic implications

Rudists from the Cretaceous fore-arc basin sequences of the Ono area in California along the western margin of the North American Craton (e.g., Nilsen, 1986; Umhoefer, 2003), clearly indicate the occurrence of canaliculate rudists in the mid-latitudes of the Northeast Pacific. These Californian canaliculate rudists most probably belong to the Caprinuloidinae. The Caprinuloidinae were widely distributed in the Caribbean region in the Barremian–early Cenomanian, and diversified markedly in the Middle–Late Albian (Palmer, 1928; Coogan, 1973; Alencáster and Aguilar-Pérez, 1996; Alencáster, 1998; Alencáster and Oviedo-García, 1998; Filkorn, 2002; Scott, 2002; Pantoja-Alor et al., 2004). Members of the subfamily have also been recorded in the Lower Aptian and Upper Albian of the central Pacific (Swinburne and Masse, 1995; Chartrousse and Masse, 1998), and in the Early Albian of Baja California (Masse et al., 2007a). Since previous records of Late Albian caprinuloidinids are restricted to the Caribbean and central Pacific, it is suggested that a faunal connection existed between the Northeast Pacific and these regions at that time. New data on Early Cretaceous trigoniids (Scott, 2007) also supports this hypothesis of a connection between the Caribbean and the Northeast Pacific.

Kodama and Ward (2001) reviewed the distribution of Late Campanian–Early Maastrichtian *Coralliochama* from Baja California and the coastal region of northern California, and suggested that coastal upwelling at around paleolatitude 43°N, which was recorded in the latest Cretaceous Marca Shale, possibly determined the northern limit of the rudist distribution at that time. The Ono area is located in almost the same present-day latitude (about 40°N) as the *Coralliochama* localities in the coastal region of Northern California.

However, the former is located to the east of the San Andreas Fault and the latter to the west of it. Considering the Neogene dextral movement of the San Andreas Fault (Matthews, 1976), the Ono area was probably located in a more northern position (at least about 3 degrees in latitude) than the *Coralliochama* localities of the coastal region of northern California. Thus rudist occurrences from the Ono area suggest that rudists were distributed further north in the Late Albian than in the Campanian-Maastrichtian along the Pacific side of the North American Continent. Nevertheless, a canaliculate (probably antillocaprinid) rudist reached much further north to Saskatchewan, Canada along the Western Interior Seaway in the Late Campanian (Caldwell and Evans, 1963; Cobban et al., 1991). Its provisional taxonomic comparison with *Ichthyosarcolithes coraloidea* (Hall and Meek) by Caldwell and Evans (1963) needs further revision, because no clear diagnostic character of the genus was provided; its Campanian age is very different from that of the Ichthyosarcolithidae; All previous reliable records of this genus except *I. coraloidea* are probably limited to the Old World (Steuber, 2002).

Recently Iba and Sano (2007, 2008) analyzed the temporal distribution of rudists, other carbonate platform biota and a Tethyan non-rudist bivalve (*Neithea*) in the Northwest Pacific margin (Russian Far East, Japan, and Taiwan), and suggested that the latter area belonged to the Tethyan Realm in the Early Cretaceous. Since the carbonate platform biota of Iba and Sano (2007) were usually recovered from shallow-marine siliciclastic sequences, it is evident that occurrence of these fossils even in siliciclastic sequences is also useful for paleobiogeographic studies. Saul (1986) summarized molluscan fossil records in the Cretaceous sequences of the Pacific Coast region of North America, and then briefly discussed warming-cooling trends and faunal provinces in this region. She apparently used rudist records as important Tethyan indicators. However, details besides *Coralliochama* were not provided. Late Albian rudist records in northern California probably indicate that the mid-latitudes of the Northeast Pacific belonged to the Tethyan Realm at that time. Further studies of the temporal and geographical distribution of rudists in the Northeast Pacific will contribute to paleobiogeographic and paleoceanographic reconstruction of the Cretaceous Pacific.

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