

Paleoecology and Paleogeography of an Extensive Rhodolith Facies from the Lower Oligocene of South Georgia and North Florida

J. P. MANKER
B. D. CARTER
*Department of Geology
Georgia Southwestern College
Americus, Georgia 31709*

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An extensive areal occurrence of a Lower Oligocene rhodolith limestone has been observed in cores and outcrops extending nearly 290 km along a NE–SW trend from south-central Georgia to the Florida Panhandle. Maximum observed thickness of the limestone is 30 m. Such a tremendous accumulation of fossil rhodoliths has not been previously described in the literature. The boundaries of the rhodolith facies coincide with the edges of the Suwannee Strait, a Cretaceous to Neogene paleobathymetric low, and may be used in subsurface mapping to delimit the edge of the Strait.

Most of the rhodoliths are Archaeolithothamnium with a mean diameter of 5 cm and most (95%) are spherical (compact) in shape. Rhodolith shape plus their internal laminar growth pattern indicate exposure to high-energy environments, resulting in frequent movement of the algae.

The occurrence of Archaeolithothamnium, along with the red alga Lithoporella and a dasycladacean alga, suggest moderate to shallow water depth. Rhodoliths overwhelmingly dominated the marine biotic community because the coarse, mobile substrate they produced precluded the development of a more diverse faunal assemblage. Species that did live within the rhodolith facies had specific adaptations for survival on such a substrate including the ability to encrust (corals and ectoprocts), bore (Lithophaga), live interstitially (Lima), and ease of mobility (scallops, echinoids).

INTRODUCTION

The purpose of this paper is to show how the interpretation of outcrops and cores containing Oligocene age rhodoliths has aided in determining the position of a buried seaway known as the Suwannee Strait. To make this determination, we first described an unusually large areal occurrence of an Oligocene rhodolith facies, and then determined the paleoecological implications of the rhodoliths, associated fauna, and sedimentary facies examined in outcrop and core. Using modern rhodolith deposits as a guide, we inferred the position of the Suwannee Strait. The Strait has been described by Applin and Applin (1944) as “a channel or trough extending southwestward across Georgia through the Tallahassee area of Florida to the Gulf of Mexico”. Although the seaway existed from the Late Cretaceous (Hull, 1962) to Eocene (Chen, 1965; McKinney, 1984), the exact location of the Strait during the Tertiary has been a matter of debate.

Reports concerning coralline algal nodules, named rhodolites by Bosellini and Ginsburg (1971), can be found in the literature beginning in the late

nineteenth century. Early studies (Kjellman, 1883; Foslie, 1894) dealt mostly with the descriptive and taxonomic aspect of these algae that grow as detached, individual, primary nodules. More recent work has been directed towards the ecological relationships of rhodoliths. To this end, several investigators (Logan, et al., 1969; Bosellini and Ginsburg, 1971; Adey and Macintyre, 1973; Focke and Gebelein, 1978; Bosence, 1985) have observed the nodules in Recent environments, thereby providing basic information for paleoenvironmental interpretations. Data from these studies have been used by others (Siesser, 1972; Toomey, 1975; Orszag-Sperber, Poignant, and Poisson, 1977; Paland Dutta, 1979; Bourrouilh-le-Jan, 1979) to describe environmental conditions of ancient rhodolith-bearing strata.

Two significant problems are encountered when attempting paleoenvironmental statements based on the presence of a certain algal form. Because classification is based on cell and reproductive structures observed in thin section, identification of the genus can be quite difficult where replacement or dolomitization has taken place. Also, because most of the rhodolith genera have wide, overlapping ranges of ecological tolerances; depth zonation, light penetration, wave energy, and water temperatures cannot be sharply delineated. As a result of these difficulties Adey and Macintyre (1973) state that in paleoecological studies “many erroneous or

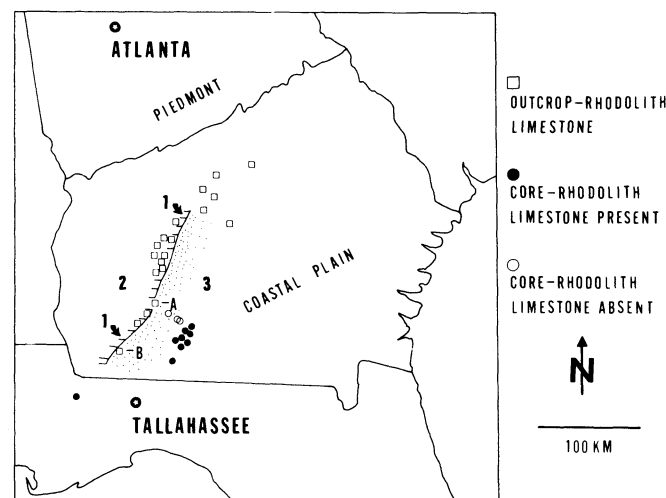


FIGURE 1—Study area showing locations of outcrops and cores that contain rhodoliths. Major sampling areas are (A) Bridgeboro Quarry and (B) Climax Cave. General physiographic features are (1) Pelham Escarpment, (2) Dougherty Plain, and (3) Tifton Upland.

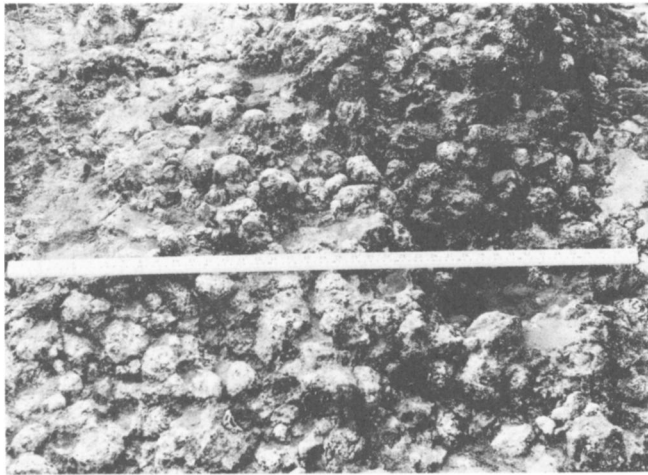


FIGURE 2—Densely packed mass of algal rhodoliths at Bridgeboro Quarry (Fig. 1, Location A). Scale is 1m.

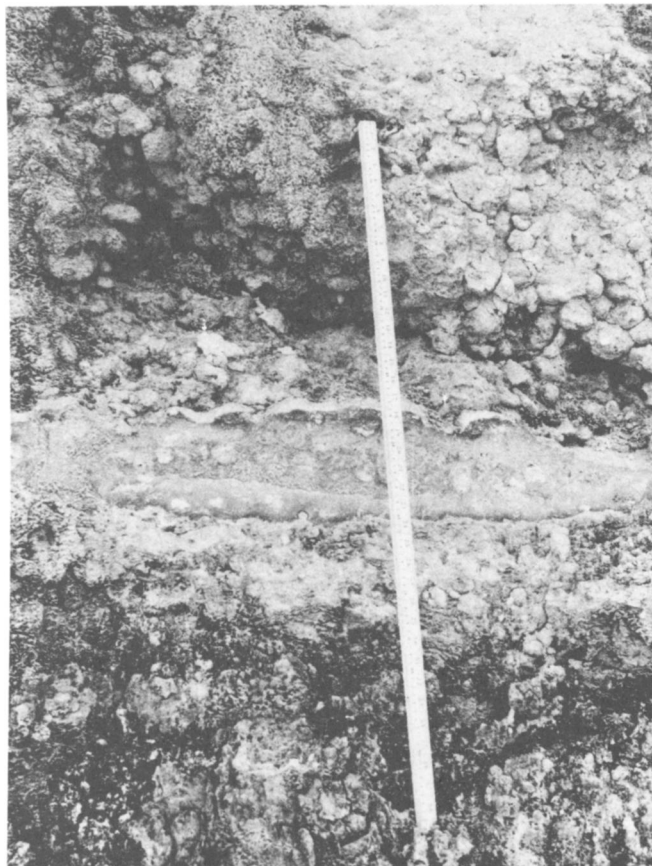


FIGURE 3—Silica replacement of rhodoliths at Bridgeboro Quarry. Note relict nodules within bedded chert. Scale is 1m.

misleading ecological and paleoecological statements and conclusions have resulted.”

GENERAL GEOLOGIC AND PHYSIOGRAPHIC SETTING

Rhodoliths were studied from cores and from a series of outcrops that extend along a NE–SW trend for nearly 290 km (Fig. 1). The entire study area encompassed approximately 26,300 sq. km of the Gulf Coastal Plain. The majority of these outcrops lie near the base of the Pelham Escarpment, which is a west-facing cuesta (Fig. 1, no. 1). The relief of this escarpment is approximately 50 m in the extreme southwestern corner of Georgia and decreases progressively northward until the escarpment swings eastward where it becomes difficult to define. Whether this topographic feature is a primary structure directly related to the algal limestone (i.e., a carbonate build-up), or an erosional remnant remains to be seen. To the northwest of the Pelham Escarpment lies the Dougherty Plain (Fig. 1, no. 2), which is underlain by the Eocene Ocala Group and thin Oligocene carbonates and residuum (Pickering et al., 1976; Huddleston, 1981). To the southeast lies the topographically higher Tifton Upland (Fig. 1, no. 3), which is underlain by post-Oligocene fluviodeltaic and shallow-marine clastics, and locally by Oligocene carbonates.

The majority of outcrops, which are scarce and poorly exposed, consist of roadcuts, sinkholes, and caves. However, an excellent exposure exists in a quarry near Bridgeboro, Georgia (Fig. 1, Location A). Huddleston (1981) has used this exposure as the type locality for an informal unit that he calls the Bridgeboro limestone.

RHODOLITHS

Outcrop and Megascopic Description

Unless otherwise noted the following descriptions are based on observations made at the Bridgeboro, Georgia, quarry.

The 21 meters of exposed limestone is dominated by a densely packed mass of algal rhodoliths (Fig. 2). Field measurements show approximately 294 rhodoliths/m² in general, the number of rhodoliths remains nearly constant

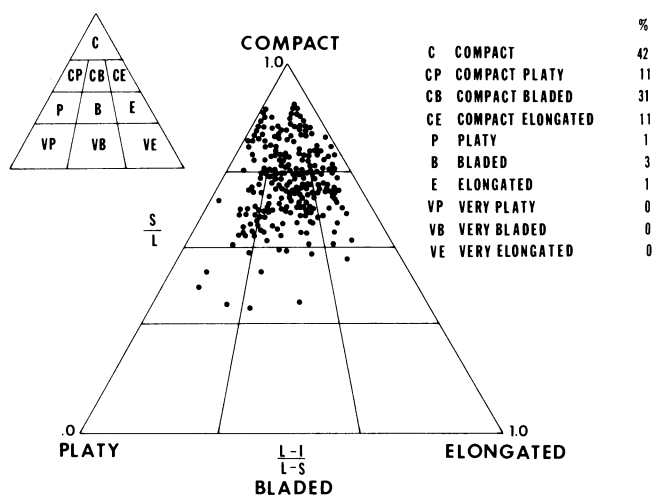


FIGURE 4—Results of shape analysis of 278 rhodoliths collected from Bridgeboro Quarry.

diffraction (XRD) analysis shows the clay to be a smectite, which swells to 17Å upon glycol solvation (Bowman and Manker, 1982).

Rhodoliths were collected from four horizons within the quarry: 0 m, 4.5 m, 9 m, and 21 m from the top of the quarry.

Compared to living specimens collected by Bosellini and Ginsburg (1971), the surfaces of the rhodoliths collected in this study were relatively smooth. This smoothness may be the result of matrix caught between the knobs and protuberances on the nodule's surface that masks the original bumpiness.

The arithmetic mean diameter was calculated for each of the 278 rhodoliths by measuring their long (L), intermediate (I), and short (S) axial lengths and by employing the formula $D_m = (L + I + S)/3$. Mean diameters for the rhodoliths ranged from 8.4–2.1 cm. By employing

TABLE 1—Summary of mean diameters and size-sorting values for rhodoliths versus collection depth within Bridgeboro Quarry.

depth (m)	mean diameter (cm)	sorting (σ_1)
0	4.3	0.8 ϕ
4.5	4.9	1.3 ϕ
9.0	4.8	1.0 ϕ
21.0	5.7	1.1 ϕ

throughout most of the section; however, some variations have been noted. Three (~1–3 m thick) zones of matrix-rich, algal-poor beds (≤ 40 rhodoliths/m²) occur within the quarry section. One of these zones corresponds to the upper 2 meters of the section and was sampled for paleoecologic analyses. The number of rhodoliths also varies laterally within the limits given above.

Compared to the rhodoliths the enclosing matrix is relatively soft, thereby facilitating the collection of algae for laboratory investigation. Throughout the exposed section, but most noticeably in the upper 15 meters, rhodoliths and enclosing carbonate sand matrix have in part been replaced by chert (Fig. 3).

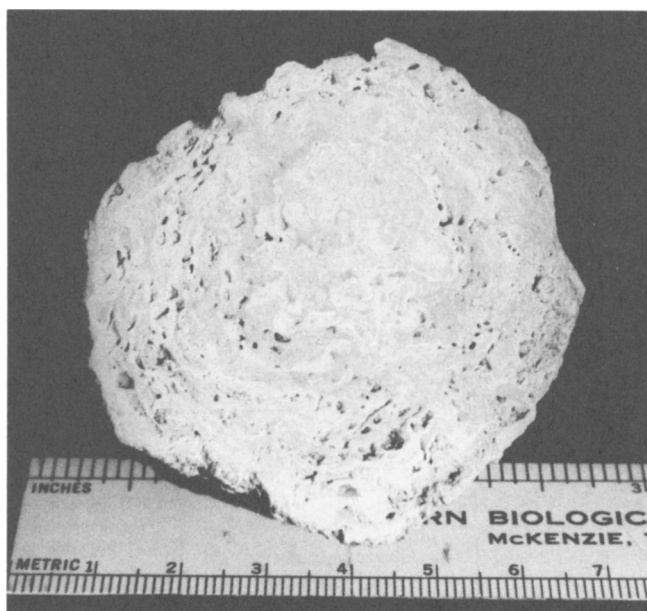


FIGURE 5—Internal structure of a rhodolith from Bridgeboro Quarry. Note the laminar growth pattern.

Although silicification occurred in discrete beds 0.5–1.0 m thick, these chert beds are not continuous throughout the quarry. Lenses and pockets of a yellowish-green clay intercalated with the algal limestone occurs mostly in the upper 15 meters of the section. X-ray

the methods of moments, an overall mean diameter of 5.1 cm and a standard deviation of 1.2 ϕ (poor size sorting) was calculated for all rhodoliths collected (Table 1). The mean rhodolith diameter gradually decreases with higher stratigraphic position. Standard



FIGURE 6—Sporangial sori (S) in the perithallial tissue of *Archaeolithothamnium*. Bar scale is 0.5 mm.

deviation values (sorting) show rhodoliths from the uppermost horizon (0-m level) to be moderately sorted, while those from horizons below are poorly sorted (Table 1).

Rhodolith shape was evaluated for 278 samples by using the method developed by Folk and Sneed (1958) where the axial ratios of S/L and (L-I)/(L-S) are calculated and plotted on a triangular diagram (Fig. 4). The majority of the nodules were either compact or compact bladed. The same type of plot was completed for each horizon, but no significant changes in shape versus depth were observed. In addition, there was no significant correlation between diameter and sphericity of the rhodoliths. The correlation coefficient was calculated by mathematically comparing mean diameter to maximum projection sphericity (ψ_p), where $\psi_p = (S^2/LI)^{1/3}$.

Internally, the rhodoliths display a laminar growth pattern from the center to the outermost growth layers (Fig. 5). Those with a bumpy surface show a

columnar growth pattern only in the outermost layers. In contrast to recent specimens examined by Bosellini and Ginsburg (1971), these rhodoliths are not encrusting a foreign object. A moderate number of borings of approximately 1 cm in diameter have been observed in these rhodoliths. Most of these structures were probably generated by the bivalve *Lithophaga nuda* since the remains of this bivalve were found in numerous rhodolith specimens. More abundant are smaller borings 1 mm to 2 mm in diameter, which may have been created by sponges or worms.

Normal calcite is the mineralogy of rhodoliths that are not replaced by silica. No magnesium substitution within the calcite was detected by XRD techniques, which show the 100 intensity peak (khl 104) at 3.03Å.

Microscopic Description

Thin-section analysis shows that most of the rhodoliths collected from

the quarry are of the genus *Archaeolithothamnium*. This conclusion is based on observation of sporangial sori in the perithallial tissue of the algae (Fig. 6). A minor occurrence of the genus *Lithoporella* has been observed in the matrix, within some rhodoliths from the quarry, and in some from Climax Cave (Fig. 1, Location B). Uncertain identification of a conceptacle-bearing alga, which could have been either *Lithophyllum* (Fig. 7), *Porolithon*, or *Neogoniolithon*, was made in some rhodoliths and matrix. Because the number of conceptacle pores could not be determined, positive identification could not be made.

Rhodoliths from outcrops other than the Bridgeboro Quarry were also examined in thin section. In most cases, they were replaced by silica, making positive identification of the algae impossible. However, the overall morphological features seen megascopically and in thin section were similar to those algae positively identified as *Archaeolithothamnium*.

ASSOCIATED FAUNA

Twenty-one identified species and at least 12 additional unidentified species from the Bridgeboro Quarry are listed in Table 2. As was previously mentioned, the rhodolith population decreases in the uppermost part of the section. The associated fauna near the top of the section is richer and more diverse (15 species identified) as compared to those intervals dominated by the algae (only 7 species identified).

The assemblages associated with the algae indicate an Oligocene (Vicksburgian) age for the unit exposed in the quarry. None of the genera in Table 2 are inconsistent with such an assignment. The scallops *Chlamys anatipes* and *C. duncanensis*, the foraminifer *Prorotalia mexicana* reported by Herriek (1961), and the echinoids *Clypeaster cotteai* and *Rhyncholampas gouldii* are known only from the Oligocene, with *C. anatipes* and *C. cotteai* being known only from the Vicksburgian (Cooke, 1959; Glawe, 1974). Several of the outcrops north and south of Bridgeboro can be correlated with the limestone section in the quarry based on their stratigraphic position and the presence of *Rhyncholampas gouldii* and the rhodoliths.

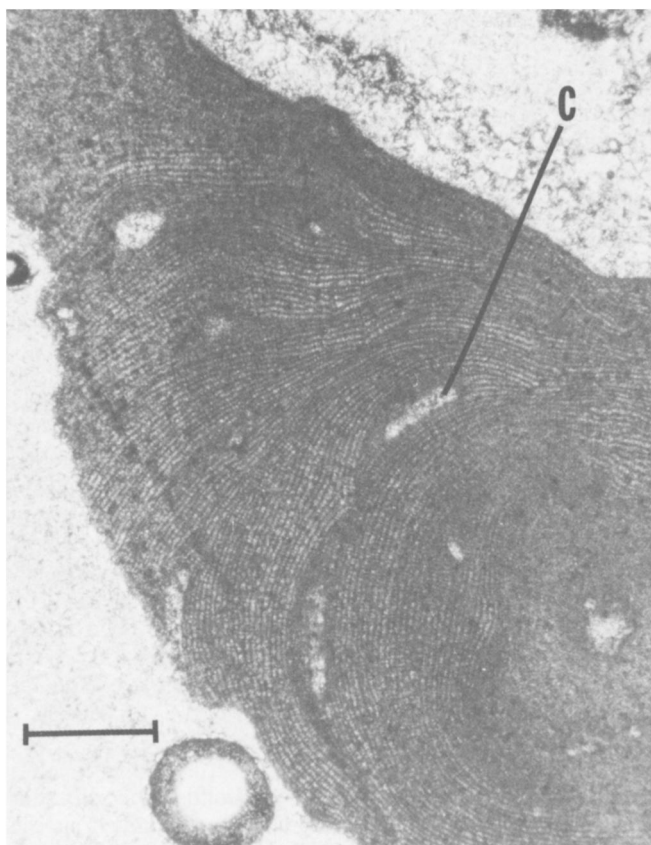


FIGURE 7—Con-ceptacle-bearing (C) alga *Lithophylum*(?) from Bridgeboro Quarry. Bar scale is 0.5mm.

PALEOECOLOGY

Thorough collection of fossils from four sites within the Bridgeboro Quarry allows paleoecological interpretations of the algae and associated fauna. Precise determinations of simple faunal diversity is difficult because most of the molluscs are preserved as molds, making identifications difficult or impossible. Thus, any attempt at measurement of diversity probably underestimates the original biotic diversity. Taphonomic bias is further complicated by the fact that some molluscan species (and other taxa) have not been preserved at all.

Algal rhodoliths are by far the dominant organisms observed. The red algae make up at least 95% of the individual fossils encountered at any one site. The most common genus is *Archaeolithothamnium*, although *Lithoporella* and one other genus of coralline alga have been encountered. One fragment of a

dasycladacean alga was found near the top of the section at the quarry. Because water-depth interpretations based on generic observations are probably imprecise, our identifications allow only very general environmental interpretations.

Both *Archaeolithothamnium* and *Lithoporella* are warm water genera with the latter being more common on tropical reefs (Adey and Macintyre, 1973; Wray, 1977). *Archaeolithothamnium* prefers, but is not restricted to, lower light intensities, which imply a deeper water environment. *Lithoporella*, because of its dominance on reefs, may indicate shallower water with greater light intensity, although no precise information for this genus has been found.

A consideration of the shape/sphericity and internal growth patterns of the rhodoliths gives some indication of depth. In a study of Recent rhodoliths, Bosellini and Ginsburg (1971) noted that

those specimens that were frequently moved by waves and currents tended to be more spherical or compact and displayed an internal laminar growth pattern. Those algae that were trapped in beds of turtle grass tended to be discoidal to flat and had a columnar growth pattern. The majority of the specimens collected during this study were compact and displayed a laminar growth pattern. This suggests that the rhodoliths grew under relatively high-energy conditions that moved them frequently, implying depths that are shallower than what might typically be expected for *Archaeolithothamnium*. The bladed to platy specimens observed in this investigation were found in association with pockets and lenses of swelling clays. They usually occurred at the bottom and in margins of the pockets, indicating that the algae had been trapped in a depression and rendered immobile. These depressions were subsequently filled with swelling clay.

Since *Lithoporella*, which is a shallow water alga, tends to be more abundant at the top of the quarry section, a change in water depth with time may be inferred. A general shoaling, either due to a sea-level change or the build-up of the algal facies, probably occurred.

Because the biota can be characterized as a low-diversity community dominated by red algae (Table 2), it may have been subjected to a type of environmental stress that would have restricted or excluded a more diverse and abundant biota. However, the kinds of species that are present (including the red algae) suggest that such stress could not have resulted from abnormal salinity, sea-water chemistry, or turbidity. The paucity of fine-grained sediment supports a low-turbidity environment, and the nature of the faunal assemblage itself implies a warm, normal marine, open-ocean setting. We suggest that the mechanism causing the low species diversity in this environment was the irregular and mobile substrate produced by the rhodoliths.

Most of the species included in Table 2 can be shown to have some specific adaptation for an irregular, mobile substrate. These adaptations include the ability to bore into or encrust upon the algae, and the ability to reside in interstices between rhodoliths. In addition,

TABLE 2—Species encountered in the rhodolith facies at the Bridgeboro Quarry.

PROTISTA	
<i>Archaeolithothamnium</i>	C
<i>Lithoporella</i> *	R/R
unidentified melobesiid*	R/R
<i>Lepidocyclus</i> sp.	C
4 species of smaller foraminifera* ¹	R
CNIDARIA	
<i>Trochocyathus</i> (?) sp.	R/R
unidentified colonial coral	R/R
ECTOPROCTA	
**encrusting cheilostomes	R
**?unidentified encruster*	R
ANNELIDA	
<i>sabellarid</i> (?) tubes	U
GASTROPODA	
<i>Cerithium</i> cf. <i>hernandoensis</i>	U
<i>Ampullina</i> cf. <i>flintensis</i>	U
<i>Conus</i> sp.	R
<i>Turritella</i> sp.	R
2 or 3 unidentified species	R?
BIVALVIA	
<i>Lithophaga nuda</i>	C
<i>Glycymeris</i> cf. <i>cookei</i>	U
<i>Chlamys duncanensis</i>	C
<i>C. anatipes</i>	R/R
<i>Ostrea</i> sp. A	U
<i>Ostrea</i> sp. B	R
<i>Lima</i> sp.	R
<i>Phacoides</i> sp.	R/R
? <i>Pitar</i> sp.	R
3 unidentified species	R?
ECHINOIDEA	
undescribed <i>Prionocidarid</i> (?)	R/R?***
<i>Clypeaster cotteau</i>	C
<i>Rhyncholampus gouldii</i>	U
undescribed <i>Brissus</i>	R

C Common. Many individuals from all 3 localities.

U Uncommon. 3–6 individuals from at least 2 localities.

R/R Rare but recurrent. 1 individual from each of 2 localities.

R Rare. Only 1 individual found.

* Known only from thin section.

** May be the same species.

*** Spines and disarticulated plates may or may not represent the same species.

¹ Herrick (1961) reports *Prorotalia mexicana* from a core through these strata just south of the quarry.

some species' mobility or large size relative to rhodoliths may have aided in their survival on the substrate.

Lithophaga nuda survived in this environment by boring into the nodular algae. Its frequent occurrence in collec-

tions (Table 2) along with the numerous borings observed in sectioned rhodoliths demonstrates its abundance.

Attachment or encrustation upon rhodoliths or other skeletal remains was another common survival strategy. The solitary coral *Trochocyathus*(?) attached to rhodoliths or dead tests of *Clypeaster cotteau*, and cheilostomes encrusted the tests of *Lepidocyclus* and rhodoliths. Sabellarid(?) worm tubes also encrusted the alga. Oysters displaying irregular attachment scars on their valves suggest that they also attached to the rhodoliths.

Chlamys duncanensis and *Chlamys anatipes* (scallops) probably relied upon their mobility and crevice-dwelling habit to cope with the shifting substratum, as do modern species of this genus (Kauffman, 1969; Stanley, 1970). *Lima* was probably byssally attached within crevices between rhodoliths. Modern species of *Lima* live interstitially in cobbly substrata (Kauffman, 1969; Stanley, 1970). *Lepidocyclus* may have also lived between the rhodoliths.

Borers and encrusters were often found in life position within the rhodolith-rich facies (Fig. 8a). This was not true, however, for other species that were large and mobile, such as *Conus* sp. and other snails, echinoids, and bivalves; these species were more frequently in life position in rhodolith-poor carbonate sands, where they were more abundant than in rhodolith-dominated environments (Fig. 8b). Therefore, their presence in the rhodolith facies may reflect post-mortem transport from a sandy environment. For example, autecological analysis of *Conus* (Kohn, 1959), *Rhyncholampus* (Mortensen, 1948a; Kier, 1962, 1975; Gladfelter, 1978), *Clypeaster* (Mortensen, 1948b), *Glycymeris*, *Pitar*, and *Phacoides* (Kauffman, 1969; Stanley, 1970), suggests that these organisms have preferences for sandy substrata. Modern species of *Brissus* also inhabit mixed sand and gravel substrata (Kier, 1984; Kier and Grant, 1965).

RHODOLITHS AND THE SUWANNEE STRAIT

Outcrops of the lower Oligocene rhodolith limestone occur in a NE–SW trend paralleling the west-facing Pel-

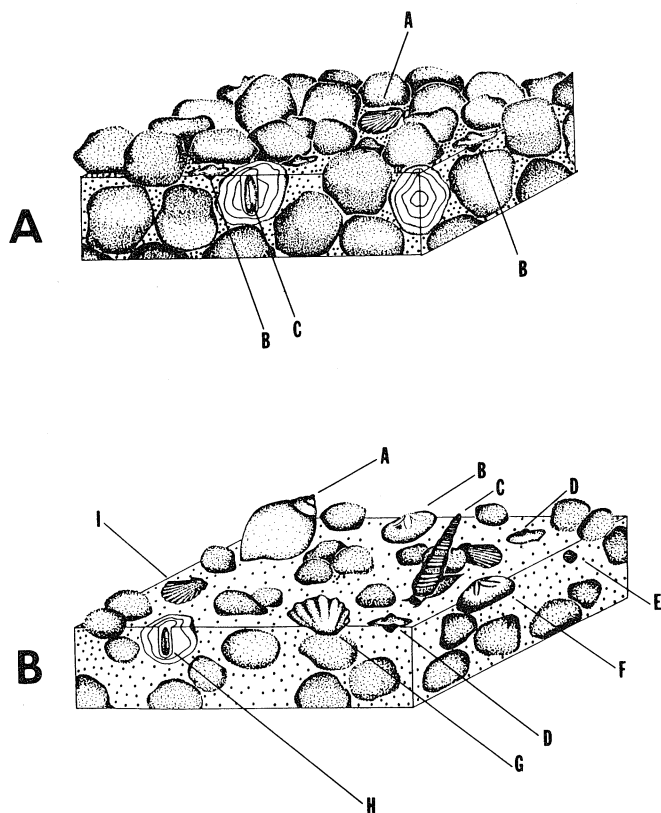


FIGURE 8A—Paleoecologic reconstruction of lower rhodolith-dominated community from Bridgeboro Quarry. Note the extreme dominance by rhodoliths and the low diversity of associated taxa. A) *Chlamys duncanensis*, B) *Lepidocyclina* sp., C) *Lithophaga nuda*. **B**) Reconstruction of uppermost beds at Bridgeboro Quarry. Note the lower rhodolith dominance and the higher diversity of associated taxa compared to Figure 8A. A) *Ampullina flintensis*, B) *Clypeaster cotteai*, C) *Cerithium hernandoensis*(?), D) *Lepidocyclina* sp., E) *Glycymeris cookei*(?), F) *Rhyncholampas gouldii*, G) oyster, H) *Lithophaga nuda*, I) *Chlamys duncanensis*.

ham Escarpment (Fig. 1). Lower Oligocene rhodolith limestone was also observed in subsurface cores (Fig. 1). Lower Oligocene micritic limestone from another series of cores was devoid of rhodoliths and contained abundant planktonic biota (Huddlestun, pers. comm., 1985), indicating a water depth greater than that at which the rhodoliths flourished.

These observations suggest the existence of two moderately shallow water environments (carbonate shelves) separated by a deeper water carbonate environment (Fig. 9). These shelves were the site of a tremendous population of rhodoliths, but the intervening deeper water environment precluded the growth of red algae. Could the deeper marine environment be the elusive Suwannee Strait? Based on the absence of rhodoliths in the cores of these Lower Oligocene rocks, plus a thickening and depression of the micritic limestone, we believe that this

deeper marine environment could, in fact, have been the Suwannee Strait.

CONCLUSION

From central Georgia to the Florida Panhandle, an extensive Lower Oligocene rhodolith limestone contains rhodoliths of the genus *Archaeolithothamnium* with minor amounts of *Lithoporella*, *Lithophylum*, *Porolithon*, and *Neogoniolithon*. These algae are overwhelmingly the most abundant fossils encountered; only 21 non-algal species are found in association with them. Of these 21 species, which are mostly molluscs, only 7 are found in those parts of the Bridgeboro where the rhodolith dominance is greatest.

The rhodoliths' shape and internal structure give insight as to the energy of the depositional system which in turn may aid in explaining the low population and diversity of the associated fauna. Rhodolith shape was mainly compact and displayed a laminar inter-

nal growth pattern. Both of these characteristics have been observed in Recent rhodoliths that were subjected to moderate energy from waves and tides, which caused the nodular algae to move along the bottom by rolling and turning. We believe that the algae observed in this study were also subjected to a moderate- or high-energy environment that in turn created a mobile substrate. The high energy and substrate mobility of this Early Oligocene benthic environment restricted the types of organisms present. To survive, an organism would have to be mobile, large (compared to rhodoliths), a borer, or an encruster to prevent being swept away. The presence of *Archaeolithothamnium*, a dasycladacean algae, and *Lithoporella* suggests that the water depth was moderately shallow (i.e., less than 100 m).

Modern rhodolith accumulations comparable with the Bridgeboro require vigorous, persistent marine currents nearby. Subsurface data indicate that the Bridgeboro rhodolith facies flanks a subsurface paleobathymetric depression known as the Suwannee Strait or Gulf Trough. According to preliminary surface mapping, rhodolith concentrations in preserved Oligocene rocks quickly drop to zero northwest of the strait (slightly west of the Pelham Escarpment, Fig. 1, no. 1). Subsurface data suggest a similar pattern southeast of the strait. Currents flowing through the strait may have been an important causative agent leading to the growth and accumulation of rhodoliths on its flanks. Further work on the paleogeographic implications of the Bridgeboro rhodoliths by Carter, Huddlestun, and Manker is in progress.

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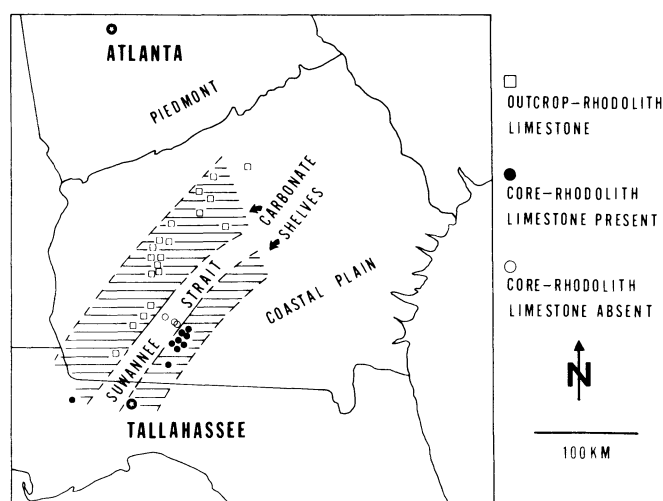


FIGURE 9—Lower Oligocene paleogeographic map showing Suwannee Strait bounded by carbonate shelves that were inhabited by a dense population of rhodoliths (*Archaeolithothamnium*).

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