

**PROCEEDINGS OF THE
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OF THE BAHAMAS AND
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Front Cover: View to the SSE on White Cay in Grahams Harbour off the north coast of San Salvador, Bahamas. At this spectacularly scenic site one can see that marine erosion has removed the entire windward portion of these early Holocene eolianites (North Point Member, with an alochem age of ~5000 radiocarbon years B.P.) that were deposited when sea level was at least 2 meters below its present position.

Back Cover: Stephen Jay Gould, keynote speaker for this symposium, holds a *Cerion rodregoi* at the Chicago Herald Tribune's 1891 monument to the landfall of Christopher Columbus, which is located on the windward coast of Crab Cay on the eastern side of San Salvador Island, Bahamas. The monument consists of an obelisk constructed from local limestone which houses a carved rock sphere depicting the globe with the continents. The inscription carved in a marble slab, reads: "On this spot, Christopher Columbus first set foot upon the soil of the New World."

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ICHTHOLOGY OF AN INTERTIDAL CARBONATE SAND FLAT: PIGEON CREEK, SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Burrowing by thalassinidean shrimp in modern tropical, shallow subtidal to intertidal carbonate environments is common, and is a powerful agent of sediment modification. Deep and intense burrowing by callianassids occurs on the intertidal margins of Pigeon Creek. There, extensive sand flats along both the south and north arms of this slightly hypersaline lagoon are thoroughly bioturbated by the callianassid shrimp *Glypturus acanthochirus*. In addition to dominating the deep burrow tier, the burrowing activity of these callianassids results in the formation of a highly mounded intertidal surface. Burrow cones commonly coalesce to form composite mound surfaces that become stabilized by the development of microbial mats. The stabilized surfaces set the stage for shallow-tier burrowers, particularly the upogebiid shrimp, *Upogebia vasquezi*, and several species of fiddler crabs, including *Uca major*. The burrows of *U. vasquezi* are thick-walled and particularly distinctive. These burrows were studied by can coring and resin casting, and their characteristics are described in detail. The geological significance of the burrows, particularly the shallow-tier burrows, is analyzed with respect to fossilization potential, occurrence as trace fossils, and significance as sea-level position indicators.

INTRODUCTION

Even novice snorkelers observing the tropical, shallow marine environments of the

Bahamas for the first time are likely to notice the sediment cones, or "volcanoes", and adjacent burrow openings, or "funnels", that are nearly ubiquitous on open to lightly grass-covered, sandy bottom areas of the shelves and lagoons of Bahamian islands. These sediment cones and funnels are formed by the burrowing activity of callianassid shrimps, fossorial decapod crustaceans that spend their entire lives in extensive burrow systems within the substrate. Such shrimps are global in occurrence, and particularly in tropical carbonate settings, their burrowing activity commonly is the dominant process in the modification of original depositional fabrics by organisms (Tudhope and Scoffin, 1984; Tedesco and Wanless, 1991; Curran, 1994). This process of sediment mixing is referred to as bioturbation.

Pigeon Creek is a large, tidally influenced, slightly hypersaline, carbonate lagoon located in the southeastern corner of San Salvador Island (Figure 1). The margins of the lagoon are fringed by mangroves that in many areas merge lagoonward with extensive intertidal sand flats. These sand flats have a "moonscape" topography of mounds and craters formed by callianassid bioturbation. Secondary burrowing by other decapods occurs on the large mounds.

The purpose of this paper is to describe the types of burrowing that occur on the Pigeon Creek sand flats. Emphasis is placed on the characteristics of the different burrows found on the mounds, particularly the distinctive burrows formed by the upogebiid

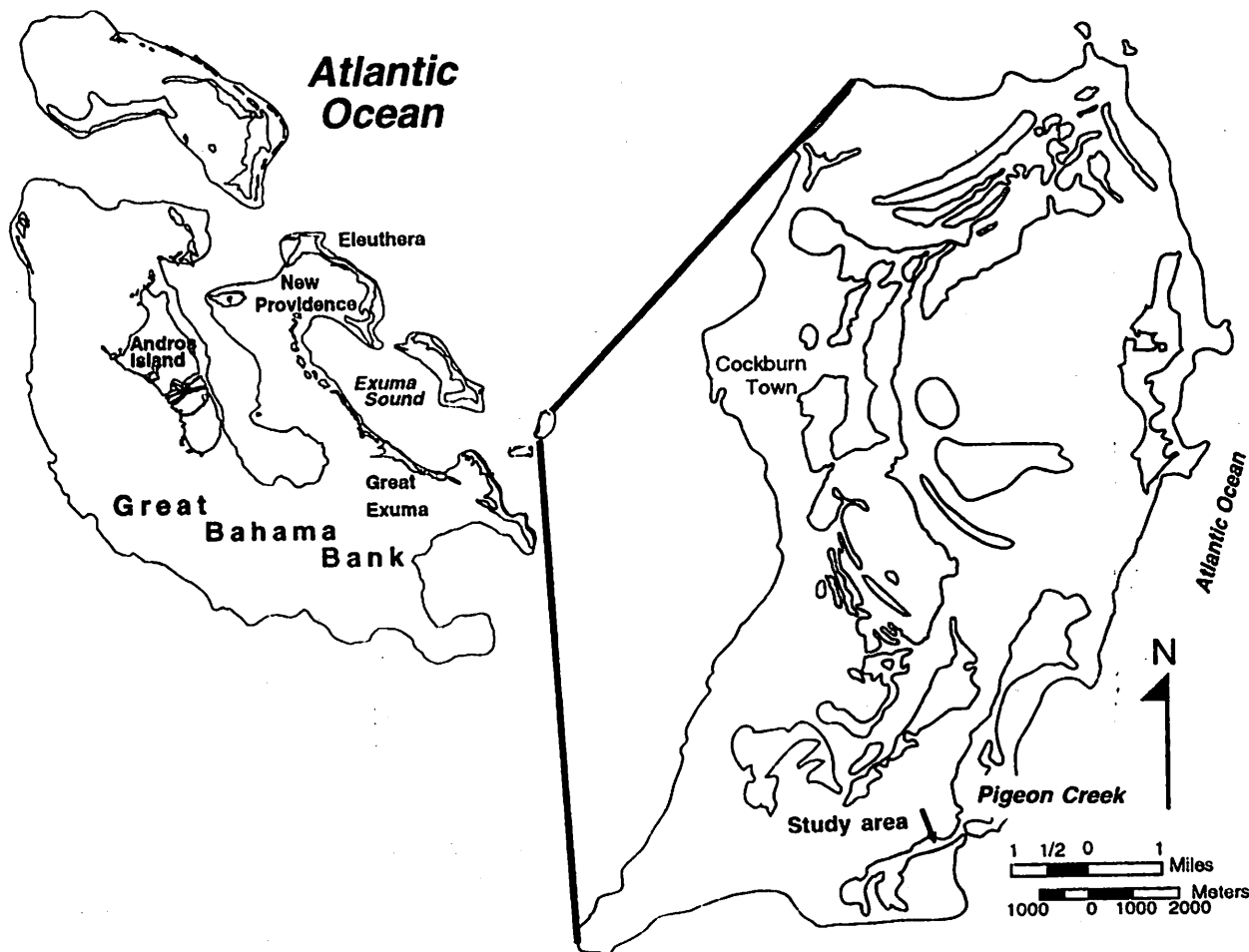


Figure 1. Location of San Salvador Island (24° N, 74° 30' W) in the Bahama Archipelago, and the study site on the south arm of Pigeon Creek.

shrimp *Upogebia vasquezii*. The potential for fossilization and the possible geologic significance of the various burrow forms also is considered. Specimens of all decapod taxa cited in this paper were identified by the junior author, and voucher specimens have been placed in the collections of the National Museum of Natural History (Smithsonian Institution), Washington, D.C.

THE STUDY AREA SETTING

Location, Hydrography, and Geology

The study area is a large, lobate, intertidal sand flat that borders the northwest bank of the south arm of Pigeon Creek, about

500 m southwest of the dock near the mouth of Pigeon Creek (Figure 1). It is essentially inaccessible from the land, but can be reached easily by boat from the dock area. The normal tidal range for this part of the lagoon is 60-75 cm, and the sand flat is completely flooded at high tide. Low tide here lags the predicted tide-table times by at least 45 minutes, and with fair weather conditions, the sand flat surface is emergent two hours before a predicted low tide. Salinity varies significantly within the Pigeon Creek system (Mitchell, 1987, Figure 4), but the flats normally are flooded by water that is at, or just slightly above, the salinity in the offshore zone (typically 36-37 ‰).

The main channel area of the south

arm of Pigeon Creek is confined and underlain by late Pleistocene limestone (the bedrock of Figure 2). Adjacent to the study area, the channel is deep and has a swiftly moving, reversing tidal current. The bank of the channel across from the sand flat is well-lithified late Pleistocene limestone. Farther to the south, the lagoon opens up considerably and shallows. Here the lagoon is bounded to the east by Holocene beach and dunal sediments of the Sandy Hook strand plain; its development and relationship to formation of the south arm of the lagoon was studied in detail by Carney et al. (1993).

Extensive intertidal sand flats border much of the north arm of Pigeon Creek, and they exhibit essentially identical sedimentologic and ichnologic characteristics to those in the study area. These flats can be reached most easily from the road near the localities marked Old Place Settlement and Pigeon Cay on the topographic map of San Salvador.

Sediments and Sand Flat Zonation

General Sediment Characteristics.

Sediments of the Pigeon Creek lagoon have been studied in some detail (Mitchell, 1987; Cummins et al., 1995). Mitchell (1987, Figure 7) defined 12 lithofacies in the lagoon complex, based on differences in mean grain size and dominant grain morphotypes. Our sand flat study area lies in Mitchell's *Halimeda* sand lithofacies. By contrast, using essentially the same criteria, Cummins et al. (1995) recognized 4 lithofacies in the south arm of Pigeon Creek. The study area corresponds to sample site 21 of Cummins et al. (1995), and appears to lie in their *Halimeda*-rich "packstone" facies. There is some doubt about that assignment because sample site 21 does not seem to plot in their Figure 6 cluster diagram. Although we have not performed a detailed analysis of the sediments from the flat, our samples show the it to be composed dominantly of very fine to fine carbonate sand, with a medium sand and larger grain component consisting of peloids and fragments of foraminifera, molluscs, and *Halimeda*. The dominant recognizable skeletal grains are fragments of large forams, cerithiid gastropods, and *Halimeda*. The mud

component ranges from < 10% to slightly >20%, with an average of ~10%. This sediment is highly bioturbated. Can cores taken from the flat show no primary sedimentary structures whatsoever; and the sediment has a homogenous to mottled appearance resulting from the prodigious burrowing activity.

Sediment Thickness.

Early in the study, a 190 m-long master transect line was established from the red mangrove fringe across the widest part of the sand flat (Figures 2, 3). Stakes were placed along the line at 25 m intervals (Figure 4A), and a detailed survey of the topography and zonation of the flat was made (Figures 2, 3). The master transect extends back into the red mangroves for a distance of 90 m along a narrow channel, the surface of which is heavily burrow-mounded.

Using an expandable steel rod sediment probe, the thickness of the Holocene sediment blanket overlying Pleistocene bedrock was measured at 10 m intervals. The sediment reaches a maximum thickness of nearly 4 m on the outer part of the flat, more than 100 m from the origin-point stake at the mouth of the mangrove channel (Figure 2). Presumably all of this sediment has accumulated during the past 3,000 years; that is, since the Holocene marine transgression flooded the inner San Salvador shelf and enabled development of the Pigeon Creek lagoonal complex (Boardman et al., 1989; Carney et al., 1993).

Topography and Zonation.

The topography of the sand flat, as shown in Figures 2, 3, and 4A, results principally from the prodigious bioturbation by the callianassid shrimp *Glypturus acanthochirus*. Daily, these shrimp expel sediment from their burrows, forming sediment cones, or volcanoes, that can reach heights > 30 cm. Surface sediment enters the burrow systems through the adjacent funnels. On several occasions we placed dyed sediment into what appeared to be active burrow funnels, and in all cases the dyed sediment appeared on the surfaces of adjacent cones by the next day. With time, closely-spaced sediment cones tend to coalesce, forming large mounds that become flattened by tidal

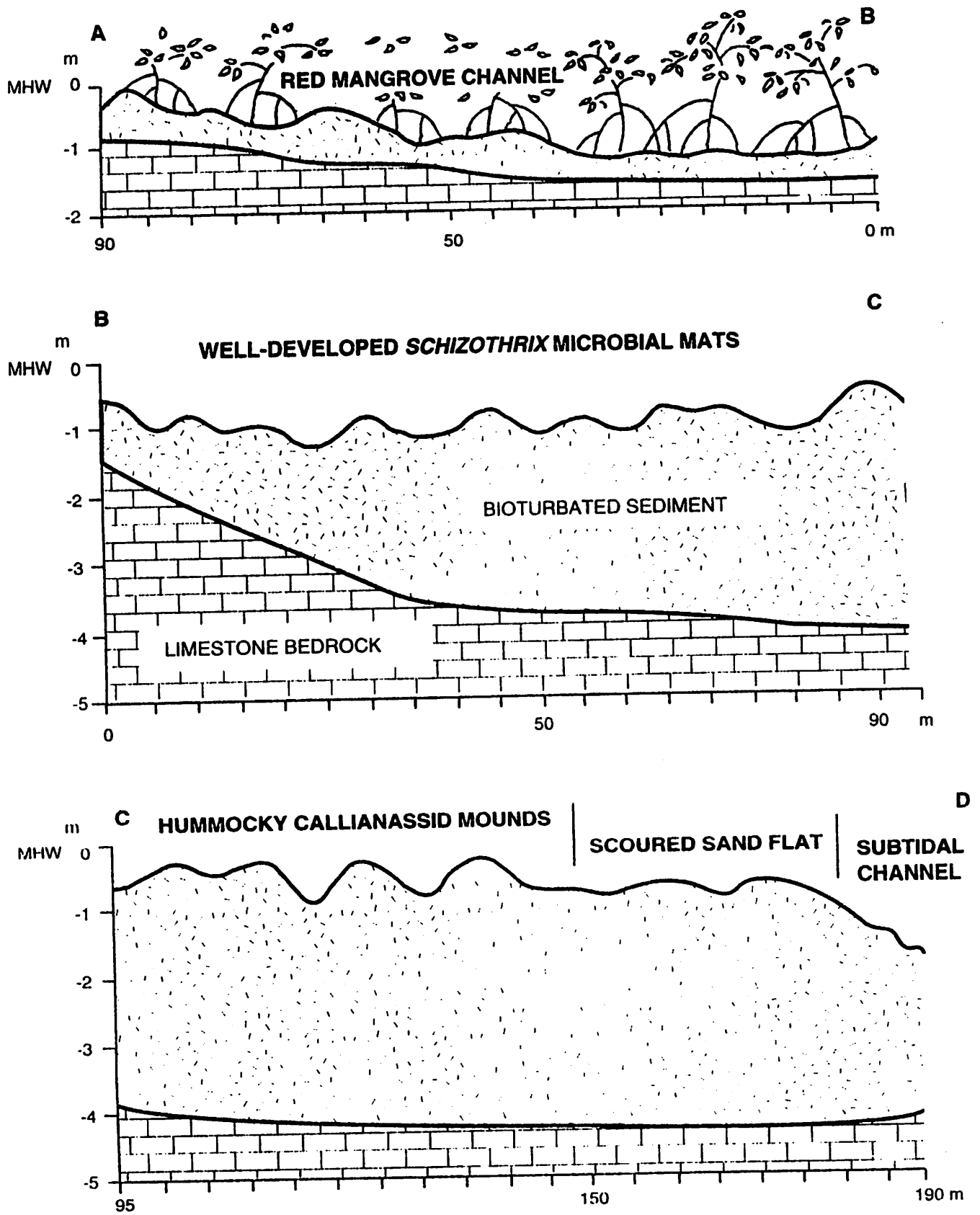


Figure 2. Profile across the study area along the master transect line showing surface topography, zonation, and the thickness of the Holocene sediment blanket overlying the late Pleistocene bedrock surface.

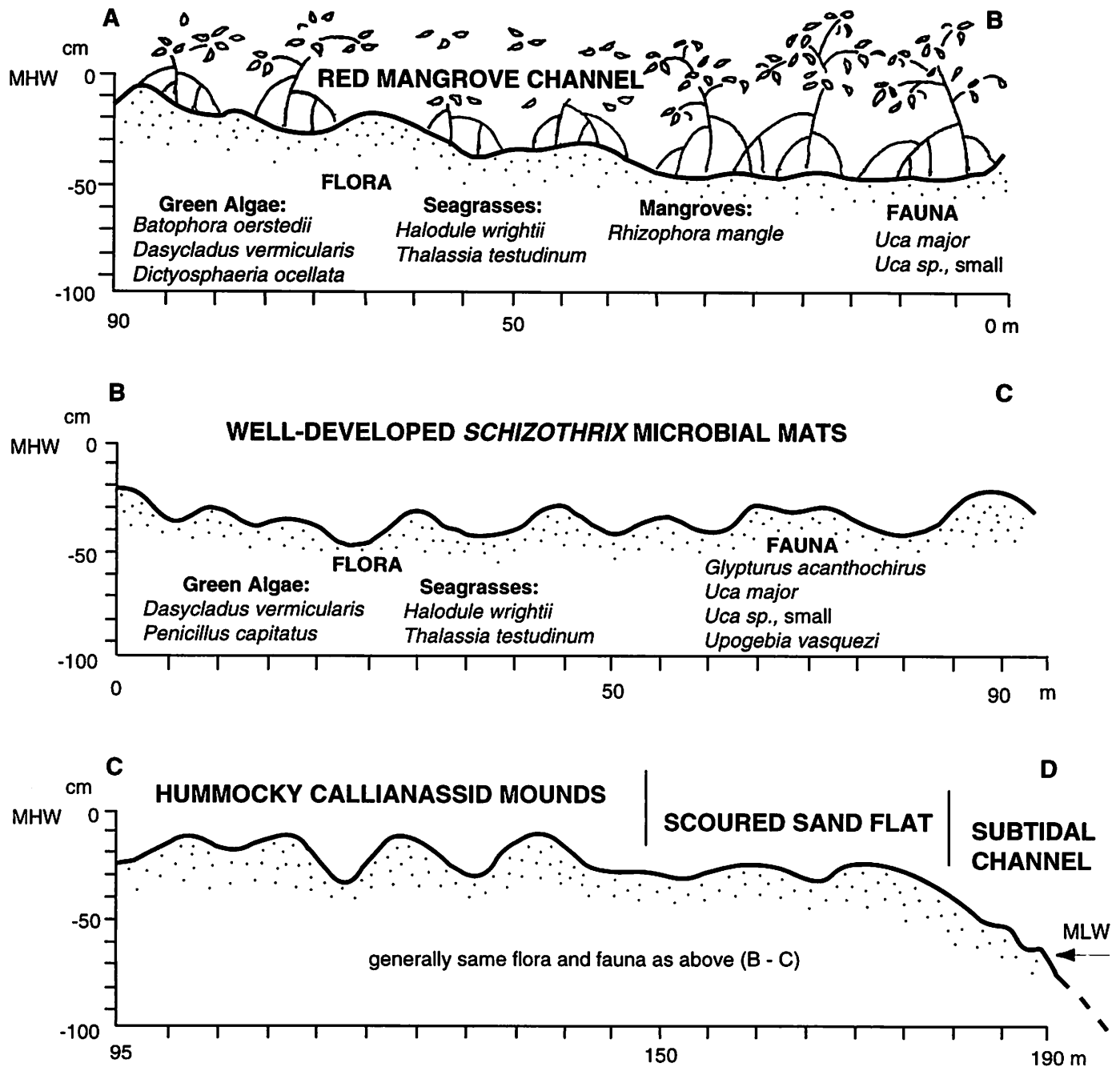


Figure 3. Profile along the master transect line showing surface topography, zonation, and occurrence of the dominant floral and infaunal species.

currents. Such mounds commonly grow to > 1 m in diameter. This is a distinctive aspect of the intertidal sand-flat environment, in that these mounds actually accrete in this setting, are long-lived, and are not destroyed by waves and currents, as would be the case in shallow

subtidal settings. Indeed, the surfaces of the large mounds are stabilized by the development of *Schizothrix*-dominated microbial mats which tend to armor the surfaces of the mounds. The result is a rather stable "moonscape" topography of mounds and

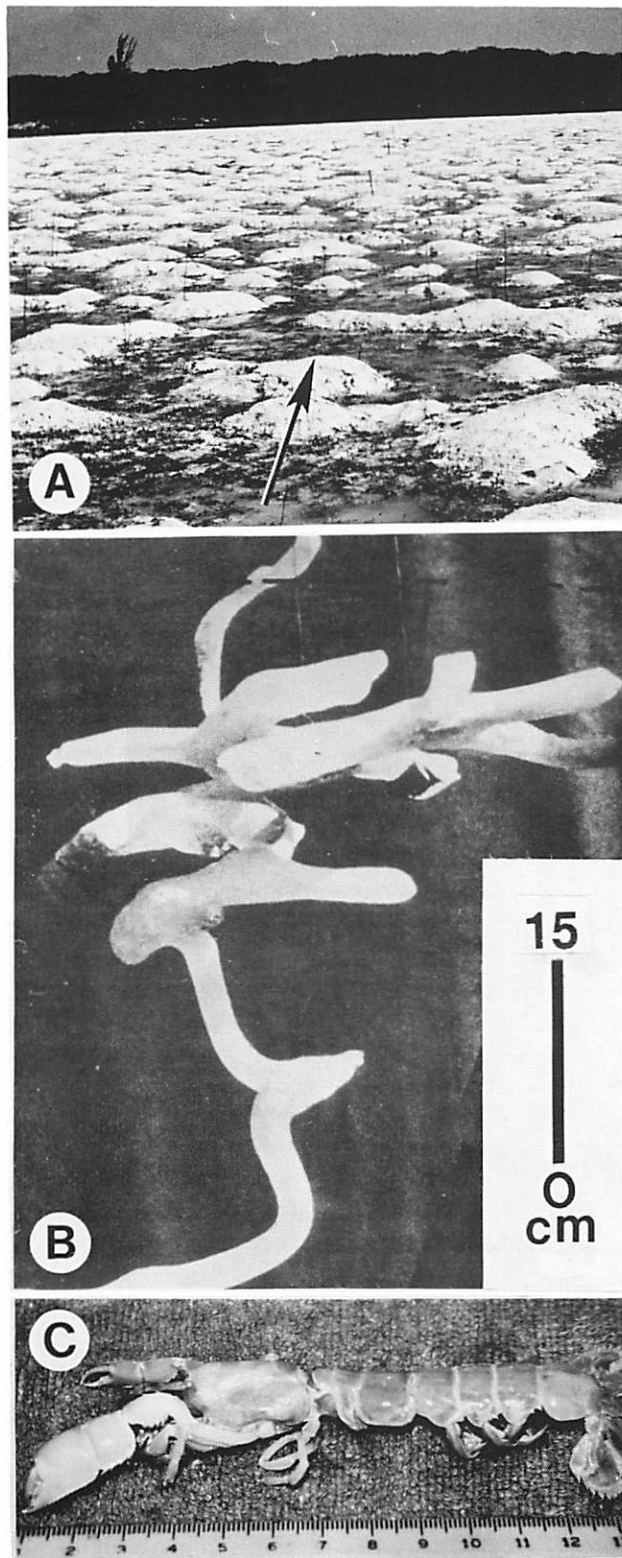


Figure 4. A) "Moonscape" topography of mounds and craters on sand flat surface bordering part of the south arm of Pigeon Creek. The arrow marks the line of the master transect across the study area. B) Resin cast of a presumed *Glypturus acanthochirus* burrow which is similar in form to those made by *G. acanthochirus* in the study area (modified from Tedesco and Wanless, 1991). C) Mature specimen of the callinassid shrimp, *Glypturus acanthochirus*.

craters, as shown in Figure 4A. In the study area, this microbial mat-stabilized surface is best developed from the edge of the red mangroves out to ~140 m on the flat (Figures 2, 3).

The outer part of the sand flat, beyond 140 m, is noticeably flatter and has a distinctly scoured appearance (i. e., relatively few fresh sediment cones). This is because of its close proximity to the main channel of Pigeon Creek, where tidal currents and small waves affect this part of the flat daily. In this area, there continues to be a significant amount of burrowing, and the surface does seem to be covered by extensive microbial matting. In fact, poorly lithified chips of mat sediment are common here. Table 1 shows that the small burrows, as discussed in the following section, are less abundant on this part of the sand flat.

Figure 3 presents a general zonation of the most common species of flora and fauna found on the sand flat. Except for the scoured areas, the flat is sparsely covered by the sea grasses *Thalassia testudinum* and *Halodule wrightii*. Because of active sediment disruption from burrowing, these grasses are excluded from the mound surfaces and are confined to the crater and small channel areas, which are ponded at low tide. Several green alga species also are found in these ponds, which can reach high temperatures, and presumably, elevated salinities during hot fair-weather days. In addition to the burrowing species, small cerithiid gastropods are abundant grazers on the coalesced mound surfaces, and some shallow-burrowing bivalves are present as well. Cummins et al. (1995) presented a detailed list of the most common molluscan species found in "normal sea grass" arew of Pigeon Creek, which in the larger sense would seem to include the mounded sand

Well-mounded Area			Sand Flat Area		
<i>Upogebia vasquezi</i>	<i>Uca major</i>	small <i>Uca spp.</i>	<i>Upogebia vasquezi</i>	<i>Uca major</i>	small <i>Uca spp.</i>
4.8	0.8	4.5	3.3	0.7	3.6
burrows / m ² n = 24 quadrats mounded area, 24 quadrats sand flat area					

Table 1. Comparison of the density of different types of shallow tier burrows on surfaces of coalesced mounds in the well-mounded section of the Pigeon Creek study area, versus the scoured section of the sand flat beyond 140 m, as shown on the profile of Figure 3.

flat area.

THE BURROWERS AND THEIR BURROW CHARACTERISTICS

Glypturus acanthochirus Stimpson, 1866

The deep-tier, sediment cone- and mound-forming burrower of the Pigeon Creek sand flat is the large callianassid shrimp, *Glypturus acanthochirus*. Although these shrimp are difficult to capture, we have had success using a yabby pump. All specimens obtained from the sand flat proper were identified as *G. acanthochirus* (Figure 4C), but more than one species of callianassid may occur along the outer edge of the flat bordering the tidal channel. In addition to *G. acanthochirus*, specimens of *Neocallichirus rathbunae* and an unidentified species were recovered. The zonation of callianassids within the whole of Pigeon Creek may be quite complex.

Glypturus acanthochirus is widespread in the shallow marine carbonate environments of the Bahamas and Caribbean, and it is thought to be a deposit feeder (Griffis and Suchanek, 1991). Sea grass found in chambers at depth within the burrow system has led to speculation that the shrimp also do some "gardening" by grazing on the microbe-rich surfaces of the decaying grass blades (Bromley, 1996).

Our experience clearly indicates that the presence of sediment cones is not sufficient evidence for identification of the species. For instance, the cones in Graham's Harbour, at the north end of San Salvador, are

made largely by a different callianassid species. No firm identification is possible without capture of actual specimens; so, there is very little firm information about the zonation of callianassids in tropical, shallow marine environments.

Recently, using resin casts, Dworschak and Ott (1993, Figure 7) described in some detail the burrow form characteristics of *Glypturus acanthochirus* from Belize. Shafts extend down from funnel (incurrent) openings, and typically at 30–50 cm beneath the surface, the central shaft begins to spiral, and tunnels radiate outward. This pattern extends downward for the length of the burrow systems, which commonly go to > 1 m depth. Dworschak and Ott (1993, p. 283) traced one burrow to a depth of 1.6 m. Resin casts, similar to those of Dworschak and Ott, have been made by the senior author from burrows on the Pigeon Creek flats. Casts of burrows attributed to *Callianassa*, but with an identical form to those made by *G. acanthochirus*, were figured by Shinn (1968) from Florida and the Bahamas, and by Tedesco and Wanless (1991; shown in Figure 4B herein) from Florida and the Caicos Platform.

Dworschak and Ott (1993) reported that cones have no open connection to the underlying burrow system although holes at the top commonly are open and surrounded by fecal pellets; this conforms to our observations. The burrows are lined, with a smooth interior wall and pelleted exterior. Such burrows should be readily preservable as fossils, and would be assigned to the ichnogenus *Ophiomorpha*. Although *Ophiomorpha* is widespread in late Pleistocene subtidal

grainstones of the Bahamas (Curran and White, 1991; Curran, 1994), fossils of the spiral form of the *G. acanthochirus* burrow have not yet been discovered.

Tedesco and Wanless (1991) and Dworschak and Ott (1993) reported that burrow chambers deep within the burrow system of *G. acanthochirus* can be repositories for shell and rubble material that enters the system through the funnel openings. Tedesco and Wanless (1991) demonstrated that this shell infilling process can be highly important in changing the original fabric of the sedimentary deposit, and results in a distinctive ichnofabric. We have not made deep cores across the Pigeon Creek sand flat, but we did not see evidence of this process in the numerous can cores taken across the flat. Perhaps can core penetration is too shallow. However, we suspect that at least some coarse-sediment trapping and ichnofabric generation is taking place at depth. Certainly there are abundant cerithiid gastropod shells available on the surface for transport into the burrow funnels, although there does not seem to be the large amount of shelly debris present on the Pigeon Creek surface, as was the case in the areas studied by Tedesco and Wanless (1991).

Additional questions of considerable sedimentologic interest are: at what rates can callianassids bioturbate sediment, and how long does it take for callianassids to move a given volume of sediment? The senior author currently has a sampling program underway on

the Pigeon Creek flat and in Graham's Harbour to attempt to answer these questions. The results will be the subject of a future report.

Upogebia vasquezi Ngoc-Ho, 1989

Background.

The coalesced mounds initiated by the burrowing activity of *Glypturus acanthochirus*, and stabilized by the development of microbial mats, provide an ideal habitat on the sand flat for colonization by burrowers that require a stable, relatively firm substrate surface. When one looks closely at these stabilized surfaces, burrow openings can be seen that obviously are different from the callianassid funnels. These are the burrows of upogebiid and ocypodid (fiddler crabs, genus *Uca*) decapods that form permanent and semi-permanent dwelling structures across the sand flat. Their generalized pattern of occurrence is shown in Figure 5, and abundance data are presented in Table 1.

The *Upogebia vasquezi* burrows.

There are numerous small burrow openings (2-6 mm) on the stabilized surfaces; some of the burrow openings appear to be paired, whereas others are obviously single. The paired openings, sometimes surrounded by small cylindrical fecal pellets, are the upogebiid burrows. The single openings commonly have larger sand pellets that are the feeding and excavation (even larger) pellets of

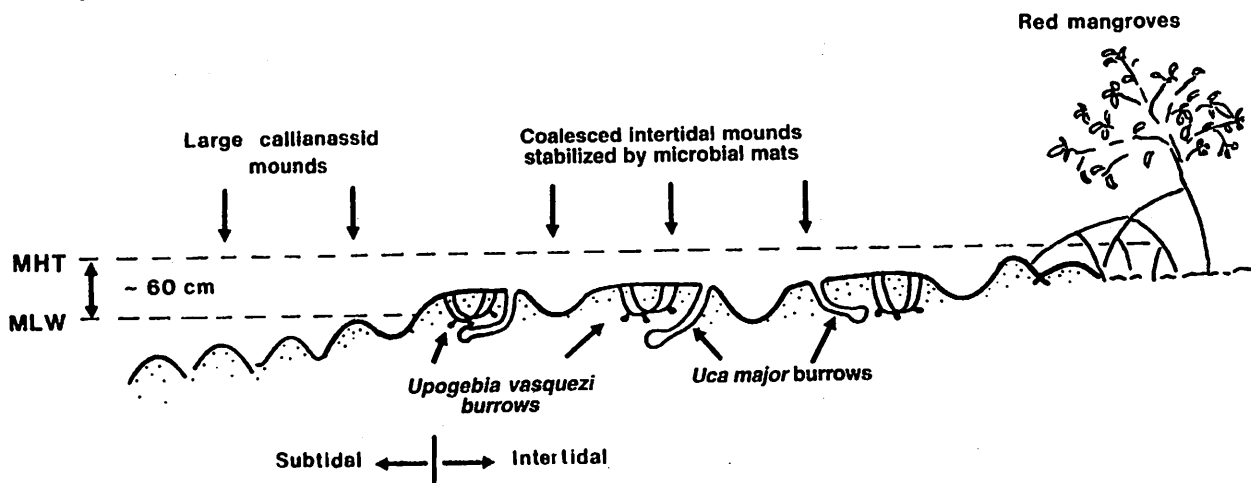


Figure 5. Generalized profile across a Pigeon Creek sand flat showing the intertidal zonation, and the position of the dominant shallow tier burrows in the coalesced mounds that were initially generated by the deep burrowing callianassids.

small fiddler crabs, *Uca* sp., discussed below.

Closer investigation of the paired openings (~2-3 cm apart) reveals that they typically have another pair close by, at a distance of 2-5 cm. Lines connecting the four openings normally make a roughly rectangular outline on the surface. Digging with a trowel reveals that there is a hard burrow structure beneath the surface, typically extending to depths of 10-15 cm. These are the burrows of *Upogebia vasquezi*. This mud shrimp burrow-maker usually can be captured by digging out the burrow system, although the burrow is destroyed in the process.

The entire burrow system can be collected by taking a can core with an open-ended one gallon paint-thinner can, or equivalent. In the lab, the burrow can be easily extracted by carefully washing the core with a gentle stream of water to remove the surrounding sediment, revealing the hard lining of the burrow system. With care, the entire burrow complex can be exposed. If allowed to air-dry, the burrow will become quite hard (see Figure 6).

Burrow casts made with polyester resin

reveal that the *Upogebia vasquezi* burrow system consists of a pair of U-shaped burrows in very close proximity to each other, sometimes actually criss-crossing (Figure 7A). At their openings, the burrows are constricted to a diameter of 5 mm or less, but they expand to a very consistent diameter of 6-10 mm just below the openings. Knob-like swellings or short tunnels of several cm length and the same diameter as the burrow shafts are found at the bases of the U's (Figure 7A, B).

This U-shaped burrow form with knobs or short tunnels at the bases of the U's is typical for upogebiid burrows (see illustrations in Bromley, 1996). What is unique about the *Upogebia vasquezi* burrow systems is their seemingly obligatory double-U form, and the incredibly thick lining of agglutinated fine to very fine carbonate sand and mud that surrounds the entire double-U. Both U's are encased in the lining (Figure 6). A single wall typically has a thickness of 1-1.5 cm, and the wall surrounding the double-U commonly reaches a combined thickness of 3-5 cm! The burrows are polished smooth on the inside by the shrimp, but the outside surface is pelleted

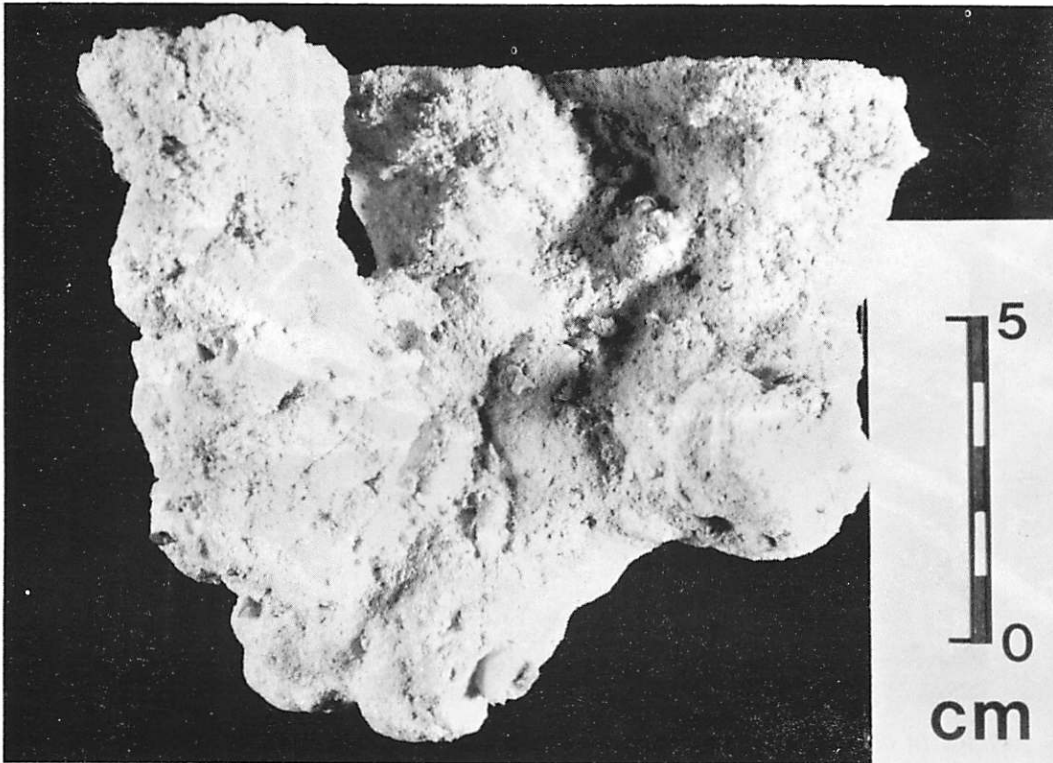


Figure 6. Exterior surface of a *Upogebia vasquezi* burrow complex extracted from a can core taken in the Pigeon Creek study area. Note the coarsely pelleted character of the exterior burrow wall.

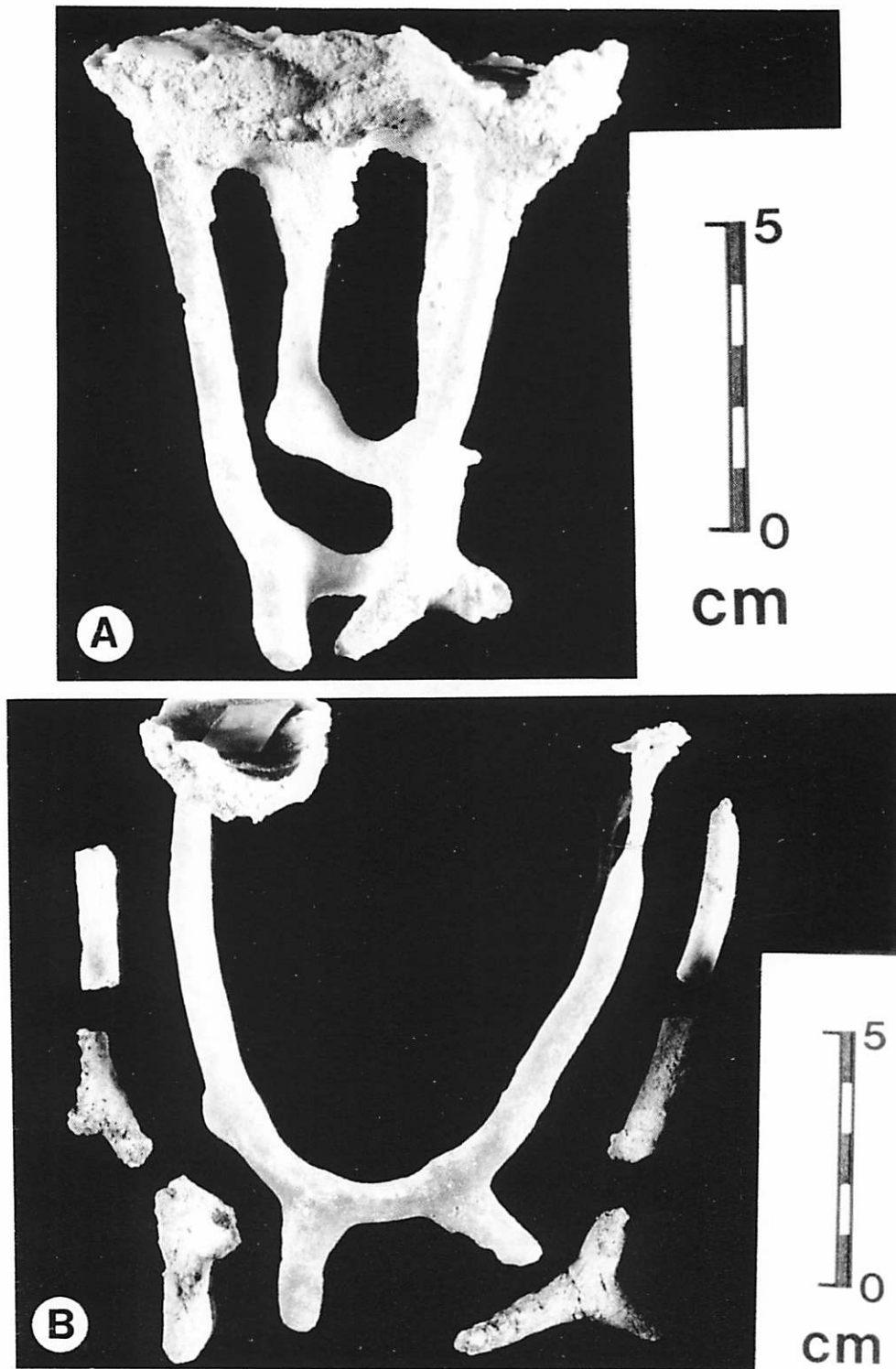


Figure 7. A) Resin cast of *Upogebia vasquezi* burrow complex from the Pigeon Creek study area showing distinctive double-U form and short tunnels at bases of the U's. B) Resin cast of modern U-form of the *U. vasquezi* burrow surrounded by similar lithified burrow-fill trace fossil segments from late Pleistocene beds on San Salvador, as described by Noble et al. (1995).

by very coarse pellets with a diameter of about 1 cm. As the shrimp typically are only 2.5-3 cm in total length, it is remarkable that they can construct such large pellets and such thick walls.

The thick, well-agglutinated walls of *Upogebia vasquezi* burrows obviously have high potential for fossilization; and in fact, fossil casts (lithified infilling sediment) have been reported in late Pleistocene lagoonal rocks from San Salvador Island (Noble et al., 1995). To date, the walls of the burrow system have not been recognized in fossil form, although the potential for such a find seems high. If such trace fossils are found, it would be tempting to assign the burrows to the ichnogenus *Ophiomorpha* based on the pelleted form of the exterior surface of the burrows; however, the burrow system architecture of these upogebiids is different from anything previously described for *Ophiomorpha*, presenting something of an ichnotaxonomic dilemma. Further geologic implications of these burrows are discussed below.

Upogebia vasquezi natural history.

Although only recently described as a new taxon, specimens now assigned to *Upogebia vasquezi* have been reported from a wide geographic range throughout the Caribbean, Bahamas, and beyond (Williams, 1993). The precise environmental setting for many of the occurrences is uncertain, but most reports seem to indicate an intertidal habitat. More information on the environmental preference of this species definitely is needed.

We have made sex determinations of shrimp carefully extracted from complete burrow systems taken in can cores (Table 2). In 11 of 12 cases, the burrow systems contained one male and one female shrimp. It is likely that a shrimp was lost in the washing process for the twelfth case. Virtually nothing is known about the function of the burrow of this species beyond what is reported here. In

this case, the burrow system seems to represent an obligatory pairing of male and female shrimps, and a cooperative effort in the construction of the burrow. The constricted form of the burrow openings indicates that the shrimp never emerge from their burrows. They are presumed to be filter feeders, as are other upogebiids. The short tunnels at the bases of the U's have been open and clean in all cases of our investigation, so they do not seem to function as repositories for grass or other debris. Indeed, we have found little if any sediment debris in active burrow systems. The walls of the burrows are polished, and the shrimp seem to be meticulous housekeepers.

There are several outstanding questions about these shrimp and their burrows. 1) What is the mating strategy for individuals of this species? The burrow tubes have no regular interconnection. 2) What is the burrow construction strategy of the seemingly obligatory male-female pair. 3) What are the energetics of the prodigious mucus production necessary to agglutinate the large pellets that form the thick burrow walls? 4) What is the function of the short tunnels at the bases of the U's; are they turnarounds, gardening areas, or other? Further detailed research will be needed to answer these questions.

Uca major (Herbst, 1782)

Also present on the stabilized surfaces of the coalesced mounds are larger burrow openings up to 3-4 cm in diameter. They can be distinguished from *Glypturus acanthochirus* burrow openings in that they do not have the characteristic funnel form, are oblique to the surface as opposed to vertical, and commonly exhibit radiate scratch marks and feeding and excavation sand pellets typical of fiddler crabs. These obliquely-oriented burrows are made by *Uca major*, a moderately large fiddler crab.

This species has a wide geographic range throughout the tropical western North

No. of Burrows	No. of Shrimp	Male : Female ratio
11	22	1:1
1	1	-

Table 2. Numbers of shrimp, and male : female ratio in burrow systems of *Upogebia vasquezi* extracted from can cores.

Atlantic and Caribbean, but it is thought to be uncommon in most areas (Crane, 1975). This is not the case on the Pigeon Creek flats, where a substantial population occurs (Table 1). The dwelling burrows are unlined, have diameters of 2-5 cm, and extend obliquely into the mound substrate following a gently meandering, somewhat irregular course for distances of up to 50 cm or more. The burrows end with a bulbous turnaround where the crab commonly is encountered. A resin cast of a typical *Uca major* burrow is shown in Figure 8.

These semi-permanent, unlined dwelling burrows have a much lower potential for preservation than the thickly-lined burrows of *Upogebia vasquezi*. As part of the shallow tier, they are likely to be destroyed by deeper-tier bioturbation accompanying the build-up of sediment during lateral accretion or marine transgression. However, the burrow walls are sufficiently coherent, that if filled and lithified, there would be a distinct boundary between the wall of the burrow and the infilling material. With this scenario, these

burrows could be preserved by a regressive event; however, at present, trace fossils of this form have not been reported from rocks of the Bahamas.

Uca spp.

As mentioned earlier, and indicated in Table 1, there are numerous small specimens of fiddlers moving over the stabilized mound surfaces of the Pigeon Creek sand flats. Undoubtedly these are good grazing surfaces. These fiddlers are active in making simple unlined burrows, with small diameter openings, that extend nearly vertically to obliquely for relatively short distances into the substrate. The burrow forms are generally similar to those described for *Uca pugilator*, the sand fiddler, common along the Atlantic coast of the United States (Allen and Curran, 1974). Rigorous specific identification of these fiddlers has not been attempted; so, they may represent a mixture of *U. major* juveniles, *U. leptodactyla* Rathbun, and *U. rapax* (Smith). The latter two species have been

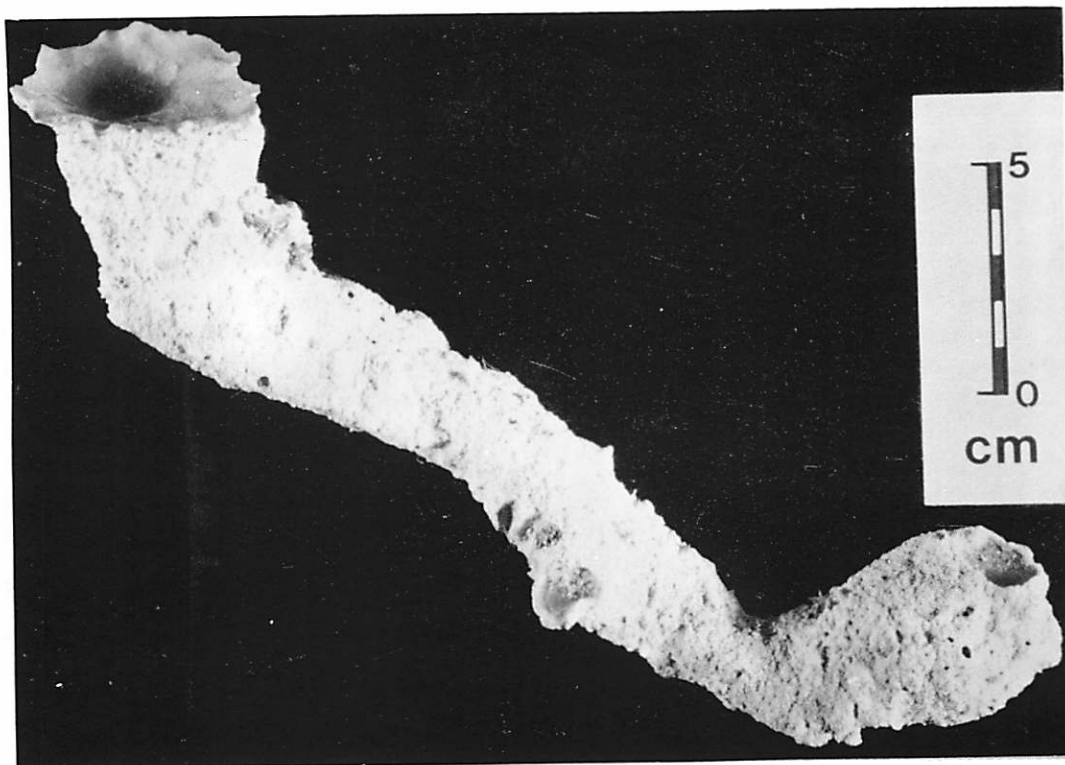


Figure 8. Resin cast of a *Uca major* burrow from a coalesced-mound surface in the Pigeon Creek study area.

identified from areas along the margins of Pigeon Creek, but specimens have not been collected from the sand flat proper. The preservation potential for these burrows is low, because they are unlined and small, and would be easily destroyed by callianassid bioturbation. They have not been reported as trace fossils in Bahamian rocks.

GEOLOGICAL IMPLICATIONS AND CONCLUSIONS

Facies representing deposition in lagoonal environments are widespread in the rock record of the Bahamas (Mitchell, 1987), and specifically on San Salvador (Noble et al., 1995). The Pigeon Creek sand flat example reported here, plus the work of Tedesco and Wanless (1991), and others, clearly illustrates that bioturbation by callianassids is a major sedimentologic process in such environments, and produces distinctive ichnofabrics. Efforts to recognize such ichnofabrics in the rock record of the Bahamas are needed.

As deep-tier burrowers, bioturbation by callianassids would destroy burrows of the shallow tier under conditions of sediment build-up that might occur with marine transgression. However, the shallow-tier burrows, particularly the thick-lined burrows of *Upogebia vasquezii*, do have good potential for fossilization, particularly under conditions of sea-level still-stand and regression. An example is provided by the work of Noble et al. (1995) on late Pleistocene rocks and shell beds in the interior of the north end of San Salvador. There, lithified burrow infill material was found in sizes and shapes nearly identical to the resin cast forms of the *U. vasquezii* burrows (Figure 7B). Based on the sediment characteristics, fossil molluscan fauna, and these trace fossils, those ancient sediments probably were deposited on a sand flat similar to the one in modern Pigeon Creek reported on here. Furthermore, given that *U. vasquezii* has a narrow intertidal range of occurrence, the trace fossils can be used as markers of a former sea-level position. The occurrence of similar trace fossils in other areas of the Bahamas, and beyond, would be highly useful in interpreting the sea-level history of the rocks containing them.

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