The Lares Limestone and Montebello Member of the Cibao Formation along Highway PR10

Field Trip Guide

by

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INTRODUCTION

Stratigraphic Nomenclature of Tertiary Rocks in Northern Puerto Rico

The Council of the New York Academy of Science sponsored the first scientific survey of Puerto Rico (Berkey, 1915). The survey included paleontology, botany, zoology, anthropology and geology. The principal geologic features of Puerto Rico are described as an *older series* of late Mesozoic rocks overlain by a *younger series* of Cenozoic rocks. The younger series was divided into two formations: the San Juan Formation and the Arecibo Formation. Later in 1919, Berkey suggested a division of the Arecibo Formation into a upper limestone member, the Quebradillas, and a lower shale member, the San Sebastián.

After Berkey's (1915) preliminary study, the New York Academy of Science divided the island into seven districts. These seven districts were assigned to different geologists. The middle Tertiary rocks of northwestern Puerto Rico were divided by Hubbard (1923) into (from oldest to youngest) the San Sebastián Shale Formation, the Lares Limestone, the Cibao Formation, the Los Puertos Formation and the Quebradillas Limestone Formation (Fig. 1). After Hubbard (1923), Zapp *et al*. (1948) divided the rocks that were younger than the Cibao Formation into the Aguada and Aymamón Limestone Formations (see Fig. 1).

In 1957, the U.S. Geological Survey and the PREDA (Department of Industrial Research of the Puerto Rico Economic Development Administration) began detailed mapping of the middle and upper Tertiary rocks that was completed in 1970. The Los Puertos Formation and Quebradillas Limestone Formation of Hubbard (1923) were renamed the Aguada Limestone Formation, Aymamón Limestone Formation and Camuy Formation (Zapp *et al.*, 1948) in Monroe's (1973) stratigraphic summary of the middle Tertiary rocks in Puerto Rico. Disagreement still existed on this matter as we can see in Meyerhoff (1975), where he used Hubbard's (1923) stratigraphic divisions (see Fig. 1).

The Aguada Limestone Formation type-section chosen by Zapp *et al.* (1948) was discovered by Monroe (1968) to be actually in Hubbard's (1920) Cibao Formation. Furthermore, Meyerhoff (1975) noted that the base of the Aguada Limestone Formation and Los Puertos Formation was at the same stratigraphic position. These two facts led to the conclusion that the Aguada Limestone Formation and Los Puertos Formation represented the same units. Monroe (1968) attempted to rectify the problem by defining a reference section for the Aguada Limestone Formation. However, Seiglie and Moussa (1975) argued that Hubbard's (1920) name had priority, first because the Aguada Limestone Formation type section was improperly defined, and second, because the essentially equivalent Los Puertos Formation was defined earlier.

An island-wide unconformity between Los Puertos Formation (Aguada Limestone) and Aymamón Limestone was described by Seiglie and Moussa (1984) and Meyerhoff et al., (1983). Meyerhoff et al., (1983) named the unit above this unconformity the Moca Limestone Formation. This unit has not been defined formally as a rock-stratigraphic unit, and the name Aymamón Limestone is still used for the unit(s) between Los Puertos Formation (Aguada Limestone) and the Quebradillas Limestone (see Fig. 1). The name Aymamón Limestone will probably be replaced if new type sections are designated. Seigle & Moussa (1975) and Meyerhoff (1975) also argued that the Camuy Formation of Monroe (1963a) is essentially similar to the Quebradillas Limestone of Hubbard (1923), even though the Quebradillas Limestone Formation is thicker than the Camuy Formation. Seigle and Moussa (1975) redefined the type section of the Quebradillas Limestone, making it essentially equivalent to the Camuy Formation. This invalidated the name "Camuy Formation " since the Quebradillas Limestone name had priority (see Fig. 1).

The stratigraphic nomenclature used here for units of the middle and upper Tertiary section will follow the nomenclature currently used by Ward *et al.*, *in press* (see Fig. 1), which follows for the most part the nomenclature used by the U.S. Geological Survey. The major stratigraphic divisions are, in ascending order: the San Sebastián Formation, the Lares Limestone, the Cibao Formation, the Aguada (Los Puertos) Limestone Formation, the Aymamón (Moca) Limestone, and the Quebradillas (Camuy) Limestone. On the eastern side of the basin, the Lares Limestone and the Cibao Formation interfinger with the Mucarabones Formation. In the west-central part of the basin, the Montebello Member of the Cibao Formation lies between the Lares Limestone and the undifferentiated Cibao Formation, but in the east-central basin, the mudstone unit, the Río Indio, and the Quebrada Arenas Limestone Members of the Cibao Formation occupy this stratigraphic position (see Fig. 1). These stratigraphic units range in age from middle Oligocene to Pliocene.

The northern limit of the North Coast Basin reaches the Puerto Rican Trench but the original southern limit of the basin is not known. The maximum thickness recorded in a well was 1,684 m at the test well 4-CPR, drilled between

Arecibo and Barceloneta (Briggs, 1961). Based on seismic data, the maximum onshore sedimentary rocks thickness may be around 2,000 m and the maximum offshore sedimentary rocks thickness may reach 2,500 m to 3,500 m (Meyerhoff *et al.*, 1983).

This field trip will be focused on the carbonate rocks of the Lares Limestone and Montebello Member of the Cibao Formation.

The Lares Limestone and Montebello Member
of the Cibao Formation

The Lares Limestone

The upper Oligocene-lower Miocene Lares Limestone overlies the San Sebastián Formation (Seiglie and Moussa, 1984). The unit is composed predominantly of thickly bedded, fine-to medium-grained calcarenite, and in most places, is found in gradational contact with the underlying San Sebastián Formation (Hartley, 1989). Less commonly, especially over the larger structural uplifts and in the areas where the San Sebastián Formation is missing, the formation rests directly on the basement (Monroe, 1980a). This lower diachronous boundary is interpreted as deposition during a marine transgression (Briggs and Gordon, 1961; Meyerhoff *et al.*, 1983).

The Lares Limestone crops out in a continuos belt of limestone in the northern coast of the island (Fig. 2). The outcrop thickness ranges from 270 m east of the Bayaney quadrangle where it has a fairly constant thickness, to a maximum thickness of 301 m in the Bayaney quadrangle (Monroe 1980a). The formation pinches out in the western and eastern edges of the outcrop belt. In the subsurface the Lares Limestone thickness ranges from 0 to 500 m (Heisel *et al.*, 1983; Hartley, 1989; Ward *et al.*, *in press*).

The Lares Limestone was deposited on a broad 25-km-wide shelf rich in marine organisms that were similar to those living in modern reef environments (Frost *et al.*, 1983). The main mass of limestone never formed a lens-like mass, but was developed as tongues of limestone projecting laterally into clastic beds (Frost *et al.*, 1983). The western and eastern boundaries of the basin are dominated by fluvial deposits (Monroe 1980a).

Frost *et al*. (1983) interpreted three cycles of reef growth from the Lares exposed section on P.R. 129. First, a reef framework of massive corals was truncated by subaerial exposure. A second cycle of fringing-reef growth also was terminated by erosion. Finally, a third cycle of reef growth developed under tectonically stable conditions and prograded seaward with backreef material and skeletal-sand shoals capping the sequence.

In the subsurface the lower to middle Lares Limestone records a continuation of a transgression that began with the upper San Sebastián Formation (Hartley, 1989). The upper Lares Limestone represents a regressive stage that lasted through deposition of the lower Montebello Member. These transgressions and regressions were identified by Hartley (1989) by recognizing differences in depositional environments between the lower, middle and upper Lares Limestone. According to Hartley (1989), the lower Lares Limestone indicates deposition in a low-energy, open-marine environment, the middle Lares Limestone formed in a shallow-marine environment, and the upper Lares Limestone lithologies represent near-shore environments.

The Lares Limestone is overlain by the undifferentiated Cibao Formation or by the different members of the Cibao Formation depending on the specific location on the northern coast of the island (see Fig. 1). In the west-central part of the Puerto Rico North Coast Basin, the Lares Limestone overlain by the Montebello Member of the Cibao Formation. This contact is easily identified on outcrop exposures by a bed of oyster shells that can range from 1 to 5 m thick (Monroe, 1980a). Individual oysters in this bed can be as much as 12 cm in diameter.

The Montebello Member of the Cibao Formation

In the west-central part of the island the boundary between the Lares Limestone and the Montebello Member of the Cibao Formation is exposed northeast of the town of Ciales and marks a change in lithologic character and thickness of the limestone (Fig. 3). In this area the Montebello Member is composed largely of foraminifers and fragments of molluskan shells and includes beds of large oysters (Monroe, 1980a). The Montebello Member is the most laterally and stratigraphically extensive member unit of the Cibao Formation and it grades to the west and east into the undifferentiated Cibao Formation marly limestones (Figs. 3 & 4). The type locality of the Montebello Member is in the Florida quadrangle 1.2 km southeast of the town of Montebello. In this area, the Montebello Member is composed of pure calcium carbonate (Monroe, 1980a).

In the subsurface, the Montebello Member is composed of shoaling-upward sequences with the basal units being dominantly shallow middle-toinner shelf deposits and the uppermost sequences composed of rocks deposited in high-energy near-shore environments (Hartley, 1989). Just above the Lares Limestone-Montebello Member contact an oyster wackestone bed forms a convenient marker between the two formations. This bed is generally from 0.9 to 4.6 m in thickness and is present over an extensive area along the Lares Limestone-Montebello Member exposures. Although evident in outcrop, the oyster layer has been difficult to locate in the subsurface suggesting that the Montebello Member pinches out downdip.

The Lares Limestone and MontebelloMember along Highway PR10

Description of the units

Sections of the Lares Limestone and Montebello Member of the Cibao Formation were exposed during the construction of the new PR10 road from Arecibo to Utuado. The new highway exposed the entire thickness of the Montebello Member in the area, making possible the construction of a continuous stratigraphic section of the unit. The first complete stratigraphic section of the Montebello Member ever measured at the surface was presented in Ramírez-Martínez, 2001 unpublished Ph.D. Thesis. Some of the results obtained follow.

The base of the Lares Limestone and its contact with the San Sebastián Formation is exposed at the intersection of the Highways PR10 and PR6621 (Fig. 5) (N18º18′52″, W66º41′05″). In this area, the San Sebastián Formation consists of poorly consolidated sandstone, siltstone, and conglomerate composed of well-rounded particles ranging from pebbles to cobbles (Fig. 6). Beds of lignite or carbonaceous clays are also present.

The top of the San Sebastián Formation contains abundant trace fossils in the form of burrows that have been filled with the limestone material from the overlying Lares Limestone. In this area the contact between the two units is sharp but undulatory (Fig. 7). At the contact, the base of the Lares Limestone consists of fossiliferous limestones with a high content of fine to medium sand grains composed mostly of quartz and weathered volcanic rock. The fossiliferous limestones in this area are composed mostly of grainstones with Lepidocyclina foraminifers, red algae, rhodolites and echinoderms. Cobbles of weathered (oxidized) volcanic rocks are aligned in a linear layer 0.6 m above the contact and follow the apparent dip of the Lares Limestone beds (Fig. 8). A singular significant depositional event seems to be suggested by the presence of this layer of oxidized volcanic cobbles.

The Lares Limestone is 17.8 m thick in this exposure. The unit is reported to reach a maximum thickness of 310 m in the Bayaney quadrangle but in the Utuado and Florida quadrangles it becomes thin and even absent (Monroe, 1980a; Fig. 4). This change in thickness is the result of the presence of a topographic high in the area composed of basement rocks of Cretaceous age (Monroe, 1980a) and San Sebastián Formation rocks (Ramírez-Martínez, 2000).

The contact between the Lares Limestone and Montebello Member units is subtle in the Utuado quadrangle but a change in lithologic character between the units was recognized by Nelson and Monroe (1966) in the Florida quadrangle. The division between stratas was defined by the presence of a bed 1 to 3 m thick composed mainly of 5 to 10 cm oysters, probably Ostrea haitensis (Nelson and Monroe, 1966; Monroe, 1980a). This oyster layer, at the basal Montebello Member, is readily identifiable throughout the studied area and was used to define the Lares Limestone-Montebello Member contact (Figs. 5 & 9).

Along PR10 the Montebello Member unit was measured to be 305 m thick (Ramírez-Martínez, 2000). Monroe (1980a) stipulated that the fullest development of the Montebello Member is near the Río Grande of Arecibo and estimated the unit to be about 200 m thick in the area. Ramírez-Martínez (2000) showed the unit is over 100 m thicker than previously estimated by Monroe.

The Montebello Member consists mostly of repetitions of coral-dominated boundstones and foraminifer-, mollusks-, red algae- and rhodolite-dominated packstones (Ramírez-Martínez, 2000). The top of the Montebello Member at PR10 was mapped at an erosional surface located at N18º23’33”, W66º41’42”, in front of the first scenic overlook from Arecibo to Utuado (Fig. 10). Above this erosional surface, starting at 10.5 m above the road, there is a bed 0.5 m thick that is packed with gastropods (Fig. 11). These gastropods were identified as belonging to the genera Pomacea and Physa (Fig. 12) (Galluzzo, personal communication, 1998). Both genera are freshwater taxa with no tolerance for salinity and are very common in freshwater units of Tertiary age throughout the Caribbean (Vokes, personal communication, 1998).

Below the highly fossiliferous bed there are units composed of carbonaceous clays intercalated with highly brecciated units. The units are separated by undulatory contacts with pinching out beds. One of these units has elongate structures that look like rhizoliths (Fig. 13). Large meter-scale circular cavities filled with fine carbonaceous mud and carbonate breccias are also present in the outcrop and probably represent solution collapse associated with subaerial exposure (Fig. 14).

Dolomite was not found in any of the units measured along the PR10 Highway. The rocks of the Lares Limestone and Montebello Member along PR10 consist mostly of pure limestones with small amounts of terrigenous materials scattered throughout the section.

Interpretations

In the San Sebastián Formation-Lares Limestone contact exposed at the intersection of the highways PR10 and PR6621 (see Figs. 5, 6 & 7) the upper San Sebastián Formation character suggests fluvial influences and shallow water. Fossils of marine or estuarine environments were not present in the section, but beds of lignite or carbonaceous clays were observed. Graham and Jarzen (1969) sampled five beds of lignite in the Highway 111 (51,860 N., 105, 150 E., San Sebastián Quadrangle) southwest of the PR10 Highway contact. These samples were 21 m below the Lares Limestone- San Sebastián Formation contact. Graham and Jarzen (1969) reported that pollen from the mangrove <u>Rhizophora</u> makes up 61-77 percent of the samples from the lignite beds. Other lignites samples collected in the same area showed dicotyledons considered by Hollick (1928) to be typical of a tropical environment generally near lagoons or estuaries in which brackish water was present.

The grainstones present at the base of the Lares Limestone along PR10 Highway as well as the presence of lignite beds, suggest deposition close to the shore in shallow water.

There is little change in lithology across the Lares Limestone- Montebello Member contact on PR10, but a few meters below the contact the upper Lares Limestone section shows two episodes of high terrigenous input. This may indicate a relatively lower sea-level during the deposition of the upper Lares Limestone in the area. Ward et al. (2002) also called for a sea-level fall during the deposition of the upper Lares Limestone.

All the lithofacies studied in Montebello Member section along PR10 Highway suggest deposition in shallow-marine environments. Variations in fossil content and lithology could have been produced by either progradation of the shelf or subtle changes in water depth. The Montebello Member section along PR10 Highway probably was deposited in middle-shelf environments.

Sequence Stratigraphy

In the Lares Limestone and Montebello Member, the fossils are mostly shallow-water forms with fairly wide stratigraphic ranges (Seiglie and Moussa, 1984; Hartley, 1989; Scharlach, 1990; Todd, 1996; Ramírez, 2000 and Ward *et al.*, *(2002)*, among others. This makes high-resolution biostratigraphy a difficult if not impossible task. The sedimentary section, however, can be subdivided into major packages that can be chronostratigraphically related based on the concepts of sequence stratigraphy (Mitchum *et al.*, 1977). These packages or depositional sequences are considered genetically related and are separated by sequence boundaries consisting of unconformities or their correlative conformities (Mitchum *et al.*, 1977). The Oligocene and Miocene sedimentary rocks (San Sebastián Formation throughout Aymamón Limestone) have been divided into five major depositional sequences by Ward *et al.*, (*2000*, Fig. 15).

The exposure surface located right at the top of the Montebello Member on the PR10 Highway supports the third sequence boundary proposed by Ward *et al.* (*2002*). They also proposed a second sequence boundary based on a widespread oyster bed that "suggests" a relative drop in sea level. The oyster bed was found to be present in the study area and serves as a marker between the Lares Limestone and Montebello Member and supports the second sequence boundary proposed by Ward *et al.* (*2002*).

The presence of this two sequence boundaries indicates that the Lares Limestone and the Montebello Member were exposed to weathering, erosion and meteoric water invasion twice before the undifferentiated Cibao Formation was deposited over them. This has important stratigraphic, diagenetic, and hydrological implications for the units involved. First, the units were probably stratigraphically thicker than today since material was lost due to weathering and erosion as well as to compaction. Second, the porosity and permeability character of the units must have change significantly during exposure. Third, an unconfined aquifer system could have been developed during the exposure in these units since the San Sebastián Formation, at the bottom of the section, acts as a hydrologic barrier.

Conclusions

An exposed section of the Montebello Member of the Cibao Formation in PR10 Highway from Arecibo to Utuado revealed cyclicity in the distribution patterns of coral-dominated, mollusks-dominated, foraminifers-dominated, and red algae/rhodolite-dominated units (Galluzzo and Ramírez, 1998). Tectonic activity, high-order sea-level fluctuations or progradation across the gently dipping carbonate platform are proposed as possible causes for the cyclicity (Galluzzo and Ramírez, 1998).

Indications of relative changes in sea level were detected. The San Sebastián Formation-Lares Limestone contact suggest a trangressional surface. Both, an oyster layer at the base of the Montebello Member and a freshwater gastropods layer 0.5 m above the top of the Montebello Member suggest subaerial exposures are present during the history of the units (regresional surfaces).

The setting for the Lares Limestone and Montebello Member often has been described as a gently dipping carbonate platform (Scharlach, 1990; Frost *et al.*, 1983; Seiglie and Moussa, 1984; Hartley 1989; Ward *et al.*, 1990; Todd, 1996; Ramírez-Martínez 2000, and Ward *et al.*, 2002, among others). The study of the exposures on PR10 Highway supports this conclusion. Terminology relating lithofacies to reef-rimmed platform environments should be avoided since there is no evidence for shelf-brake reef tracts which would have created these environments (Galluzzo and Ramírez, 1998; Ramírez Martínez 2000; and Ward *et al.*, 2002.

Field Trip Stops

Stop 1 - Figures 5, 6, 7, 16, and 17
Lares Limestone - San Sebastián Formation Contact
Intersection of the Highway PR10 and road PR6621
(Western side of the intersection)
N18º18′52″, W66º41′05″

The top of the San Sebastián Formation contains abundant trace fossils in the form of burrows that have been filled with the limestone material from the overlying Lares Limestone. In this area the contact between the two units is sharp but undulatory (see Fig. 7). At the contact, the base of the Lares Limestone consists of fossiliferous limestones with a high content of fine to medium sand grains composed mostly of quartz and weathered volcanic rock. The fossiliferous limestones in this area are composed mostly of grainstones with Lepidocyclina foraminifers, red algae, rhodolites and echinoderms. Cobbles of weathered (oxidized) volcanic rocks are aligned in a linear layer 0.6 m above the contact and follow the apparent dip of the Lares Limestone beds (Fig. 8). A singular significant depositional event seems to be suggested by the presence of this layer of oxidized volcanic cobbles.

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Stop 2 - Figures 9, 17, 18, and 19

Montebello Member – Lares Limestone Contact
Oyster Layer Unit
Intersection of the Highway PR10 and road PR6621
(Eastern side of the intersection)
N18°18'58", W66°40'51"

The contact between the Lares Limestone and Montebello Member units is subtle in the Utuado quadrangle but a change in lithologic character between the units was recognized by Nelson and Monroe (1966) in the Florida quadrangle. The division between stratas was defined by the presence of a bed 1 to 3 m thick composed mainly of 5 to 10 cm oysters, probably Ostrea haitensis (Nelson and Monroe, 1966; Monroe, 1980a). This oyster layer, at the basal Montebello Member, is readily identifiable throughout the studied area and was used to define the Lares Limestone-Montebello Member contact (Fig. 9 & 18).

Stop 3 - Figures 17, 20, and 21

Montebello Member – Jobos Formation Contact
At the intersection of the Highway PR10 and road PR621
N18°19'58", W66°40'42"

At this stop the Montebello Member is in contact with the Jobos Formation (Upper Paleocene to Middle Eocene, mostly volcanic breccia, includes some conglomerate, volcanic sandstone, and lava 1,700m). The contact is undulatory with multiple truncations (Figs. 20 & 21). The Lares Limestone is absent here due to the former presence of a topographic high in the area composed of basement rocks of Cretaceous age (Monroe, 1980).

Stop 4 - Fig. 17
Montebello Member / Coral Boundstone
2nd Obervation Mogote north of theHighway
PR10 - PR621 road intersection
N18º19’58”, W66º40’42”

Recrystalized corals in growth position and surrounded by wackestones are abundant in the area. This unit is equivalent stratigraphically to the Head Coral- Boundstone present at the top of the outcrop visited in Stop 1.

Stop 5 - Fig. 17
Montebello Member / *Stlylophora* Boundstone
N18º20’15”, W66º40’35”

This is the only lens-like structure found in the whole PR10 Highway section. It is composed of the branching coral (*Stylophora*) and surrounded by a groundmass of red algal packstones and grainstones.

Stop 6 - Fig. 17
Montebello Member / *Porites* Boundstone
PR10 Km 70.5

The branching coral *Porites* is extremely abundant and seems to be in growth position. This unit is equivalent stratigraphically to the Branching Coral-Boundstone present at the top of the outcrop visited at Stop 1.

Stop 7 - Fig. 17
Montebello Member / *Miocerites* Packstone

N18º21'06", W66º41'12"

The study of the exposed section of the Montebello Member of the Cibao Formation in the new PR10 Highway from Arecibo to Utuado revealed cyclicity in the distribution patterns of coral-dominated, mollusks-dominated, foraminifers-dominated, and red algae/rhodolite-dominated units (Galluzzo and Ramírez, 1998). Here we have one of the multiple foraminifers-dominated packstones present in the section. The foram genus *Miocerites* is dominant. Oysters and equinodems are also common.

Stop 8 - Fig. 17 and 22
Montebello Member / Grainstone – Submarine Hardground.
N18º21'12", W66º41'12"

A 0.5 meter thick grainstone unit with abundant rhodolites, equinoderm fragments and spicules forms a sharp, linear, well defined bed in this area. The geometry of the bed, texture, and petrography suggest that this unit could have been a submarine hardground at some moment during the deposition of these rocks.

Stop 9 - Fig. 17, 23 and 24
Montebello Member / Ancient Water Table or Exposure ?
N18º22'17", W66º41'39"

A bed of carbonaceous clays is present in between the fossiliferous limestones in this outcrop. This highly undulatory bed is not associated with calishe layers, brackish or freshwater fossils, nor it has any other feature that would suggest that it was formed by subaerial exposure. Several possible explanations could be suggested to explain the formation of this atypical bed in the area. Diagenetical explanations seem more feasible than depositional. One possibility is that this layer could have mark the position of the air-water interface (water table) present in the area at some moment in time.

Stop 10 - Fig 17, 24, 25 and 27
Grainstone layer with abundant *Kupus incrassatus* in growth position
N18º22'47", W66º41'56"

The *Kuphus* belong to the super family *Pholadacea,* suborden, *Dufinae,* Orden *Myoida,* suborden *Proladina,* familia *Teredinidae,* subfamilia *Kuphinae* *(*Moore, Editor (n) Mollusca, 6[2003] 1969). The *Kuphus* have an elongated tube that is mostly composed of low magnesian calcite (Fig. 27). The animal produces secretions of calcite for the protection of depredators. Most characteristic is the presence, in the upper smaller end of the tube, of two small tubes, one slightly larger than the other, that are encased in an extensive development of supplementary calcareous deposit (Vokes Tulane University). The smaller tubes house the inhalant and exhalent siphons of the animal, the one for the inhalant siphon being somewhat larger diameter than that for the exhalent one (Vokes Tulane University). Kuphus tubes are common in the North Coast Limestones and are composed of low magnesian calcite (high potential preservation). Sr isotopes have been used to obtain dates of fossils shells composed of low magnesium calcite based on well documented variations of Sr isotopes in marine water through geologic time. The former method can be applied to the *Kuphus incrasautus* tubes since they are made of low magnesium calcite. "Absolute ages" of the Kuphus tubes can help approximate the "absolute age" when a Limestone was being formed. This "absolute age" information can probably help to establish a better stratigraphic chronology of the Puerto Rico Tertiary Limestones providing that the Kuphus tubes have not being altered. Ramírez-Martínez et al. (2006 and 2008) has demonstrated they are a promising prospect to establish absolute dates along the North Coast Limestones

Stop 11 - Fig. 18 and 26
Top of Montebello Member
Exposure ! (Paleosoils/Roots/Paleokarst/Freshwater Gastropods)
N18º22′52″, W66º41′16″

The top of the Montebello Member at PR10 was mapped at an erosional surface located at N18º23′33″, W66º41′42″ (in front of the first scenic overlook from Arecibo to Utuado). Above this erosional surface, starting at 10.5 m above the road, there is a bed 0.5 m thick that is packed with gastropods (Fig. 26). These gastropods were identified as belonging to the genera Pomacea and Physa (Fig. 12) (Galluzzo, personal communication, 1998). Both genera are freshwater taxa with no tolerance for salinity and are very common in freshwater units of Tertiary age throughout the Caribbean (Vokes, personal communication, 1998).

Below the highly fossiliferous bed there are units composed of carbonaceous clays intercalated with highly brecciated units. The units are separated by undulatory contacts with pinching out beds. One of these units has elongate structures that look like rhizoliths. Large meter-scale circular cavities filled with fine carbonaceous mud and carbonate breccias are also present in the outcrop and probably represent solution collapse associated with subaerial exposure (Figs. 13, 14 & 26).

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