Chapter 2: Paleoenviromental Reconstruction of a Coastal Lagoon in the Southwestern Dominican Republic

Introduction

Coastal ecosystems, particularly lakes and marshes, are highly dynamic and are greatly influenced by the surrounding land and sea environments. The histories of these influences are often recorded in lake and marsh sediments. For example, during massive storm events, autonomous coastal bodies of water receive overwash containing ocean sediments and ocean biota. Historical salinity profiles can be created using changes in types of diatoms and other biota. These profiles can then be used to analyze the history of conductivity between coastal lakes and the ocean (Gunter 1961). Most coastal waters have some freshwater input, so fluctuations in the basin can also be recorded within the lake. When these aspects are recorded in tandem, as they are in coastal lakes and wetlands, a wealth of information can be gathered about fluctuations in the regional climate. It is these highly sensitive responses to surrounding changes and the ability to capture these responses in a clear paleorecord that make coastal lakes excellent sites for Quaternary paleoenvironmental studies. These lakes are ideal for the collection of data that can assist in understanding both sea level and climatic change.

An increasing number of paleoenvironmental studies are being conducted in coastal environments around the world, using a wide array of proxies, including X-radiography, loss on ignition, micro- and macro-biota and X-ray diffraction (XRD), but there have been relatively few sediment core paleoenvironmental studies in the eastern Caribbean, especially in coastal settings. Published papers in this region include sedimentary work in Jamaica that documents dry and wet periods in the area over the past 120,000 years (Street-Perrott et al. 1993). A 7000 year record from Laguna Tortuguero, Puerto Rico (Burney et al. 1994), was examined for microscopic charcoal and shed light on the extent of human activity in the area as recorded by the sediments. A 5000 year hurricane recorded in Laguna Playa Grande was reconstructed using particle size analysis and showed that hurricane frequency has increased at centennial and millennial time scales (Donnelly and Woodruff 2007). Two recent studies in Cuba (Peros et al. 2007a; Peros et al. 2007b) used a variety of proxies to produce a timeline of the lake’s creation and key environmental changes. Peros et al. (2007a, 2007b) have completed extensive work in Laguna de la Leche, Cuba, using LOI, pollen, stable isotopes, and several other analyses to reconstruct lake history and regional climatic shifts (Peros et al. 2007a; Peros et al. 2007b). Several studies have examined lake sediment records in Hispaniola. Lake Miragoane, Haiti is the most extensively studied location in the Caribbean to date. Researchers have constructed a detailed chronology of major droughts and periods of increased precipitation in the area. Changes in pollen and microscopic charcoal have been used to examine vegetation change and the role of human inhabitants within the area (Brenner and Binford, 1988; Hodell et al., 1991; Curtis and Hodell, 1993; Higuera-Gundy et al., 1999). Two paleoenvironmental studies based on sediments and soils have been published for the Dominican Republic; both examined highland bogs in the Cordillera Central (Horn et al. 2000; Kennedy et al. 2006). Although these studies have begun to provide detailed accounts of the study area, much research is still needed to develop a continuous history of climate change in the Caribbean, especially in lowland and coastal areas.

A key component still lacking in many of these studies is a detailed account of more recent climate variations. To date, no published studies have focused on coastal Dominican lakes or looked at the possibility of overwash deposits from hurricane events in the eastern Caribbean. Paleoenvironmental records of climate, vegetation, fire, and human history from lake sediments are still needed to complete the regional understanding of this important area of tropical America. This study reconstructs the history of a coastal lake in southwestern Dominican Republic using multiple proxies and identifies environmental and climate fluctuations recorded within the sediment record.

Methods

Site Description

The study site is a small (~ 0.25 km^2) unnamed lake located on the southwest coast of the Dominican Republic (Figure 2.1), located in the northeast of Barahona Province, on the northern edge of the Lago Enriquillo basin (18.31^o N 71.04^o W). For the purpose of this research, we informally named the lake Laguna Alejandro. The lake is shallow and relatively flat bottomed, with an average depth of 200 cm. At the eastern end of the lake, there is a small salt pan operation (Figure 2.2). Due to the distance of the operation from the sampling site, we believe it has not disturbed the sedimentary record. The lake is located in limestone bedrock and is separated from the ocean by a limestone ridge. This ridge varies from 75–100 meters wide and from 3–5 meters in height. Most of it is covered in dense thorny shrubs, with only a few areas of comparatively thin vegetation. The lake lies on the border of a large coastal region of mangroves in the Dominican Republic (Bolay 1997); however, this lake does not have a notable mangrove population. The climate of the study area is within the semi-arid to arid zone that encompasses all of the Lago Enriquillo basin. However, the Sierra de Martín García Baoruco directly abut the lake and receive significantly more rainfall than the valley and coast (Bolay 1997). This relatively small group of mountains provides fresh water to the lake via two small streams that are located in the northeastern corner of the lake. Although this area is not well known for its geothermal activity, there are some known active areas within the region (Brock et al. 1972). The lowest portion of the core extracted for this study came out of the hole significantly warmer than the rest of the core, which may be related to geothermal activity.

Field Methods

Two sequential cores were collected on 13 February 2006 from a water depth of 202 cm (figure 2.3) at the southernmost point in the lake, approximately 15 m from the barrier between the lake and the Caribbean Sea. Our purpose was to collect a sediment profile that would be used to reconstruct the history of the lake and to assess the lake's potential for paleotempestology (reconstruction of hurricane landfalls). This location near the dune barrier was chosen in order to increase the likelihood of encountering hurricane overwash deposits. We collected the cores using a Colinvaux-Vohnout piston corer and clear PVC tubes. In total, 185 cm of sediment was recovered. On initial visual inspection, the core contained layers of carbonate/silicate beach sands, organic and carbonate rich muds, and biological components such as shells. We capped the cores in the field and transported them to Virginia Tech and archived in our laboratory at 5^{o} C.

Laboratory Methods

Traditional core analysis techniques (loss on ignition, GeoTek core logger scans) were used to obtain a generalized understanding of the core's composition. We then used other techniques such as crystallography, stable isotopes, and biota, to identify specific environmental events represented within the core.

Radiocarbon Dating

We sent organic material (wood and leaf fragments) taken at 42–43 cm, 149.5 cm, and 174.5 cm to Beta Analytic Radiocarbon Dating Laboratory for accelerator mass spectrometry (AMS) radiocarbon dating. The returned dates were then calibrated using Calib Radiocarbon Calibration Program (Stuiver et al. 1993).

Loss on Ignition

We used loss on ignition (LOI) to calculate the percentage of water, organics, carbonates, and other material for each sample. For LOI, 1 cc samples were taken from every region of distinct visible changes in the core profile, for a total of 72 samples. These samples were dried and weighed, then burned at 530º C for two hours to remove all organic matter, reweighed and then burned at 950º C for two hours to remove all carbonates, and reweighed (Dean, 1974; Bengtsson & Enell, 1986).

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Geotek Core Logger

Density, fractional porosity, and magnetic susceptibility were measured, and spectral photographs were taken at the Lamont-Doharty Earth Observatory, using the Geotek core logger. All Geotek measurements were taken at 1 cm increments per automation by the instrument.

X-Radiography

The core was transported from our laboratory to the Virginia-Maryland Regional College of Veterinary Medicine where X-radiographs were taken. Although X-radiography is commonly used in analysis of sediment cores, we were not able to locate any published radiography protocol (Collins et. al. 1999). We worked with Dr. Jeryl Jones and technicians to achieve the optimal settings to provide the greatest contrast of sediment and shell material. The Osirix program (Rosset et al. 2004) was then used for viewing the images and to calculate densities for specific regions of interest.

Biota

While multiple species were identified through tests and shells within the core, only *Ammonia beccarii*, a species of foraminifera, and serpulids tubes were examined in depth. Data from other species were kept only as presence/absence or were used for comparison *Ammonia beccarii*. Foraminifera were counted in 1 gm samples of sediment taken every 5 cm between 185 cm and 150 cm. Each sample was then wet sieved at 125 µm, and the total number of *Ammonia beccarii* was counted. The total number of ostracods and other microscopic gastropod species were also counted in these samples in order to provide a point of comparison for *Ammonia beccarii* distributions (Haslett 2001, Hayward et al. 1999, Peros et al. 2007a).

Zones in which serpulid tubes were present were identified. Within each zone, serpulid growth patterns and orientations were recorded. Within the zones, other biota were tallied, and the sedimentology of the zones and contiguous areas were examined.

Stable Isotope Analysis

Stable isotopes were analyzed changes in lake geochemistry**.** Two serpulid tubes were sampled from each distinct serpulid layer. These tubes were then cleaned in a ultrasonic cleaner and the samples were cut into segments 1– 4 mm in width (Figure 2.4). Each segment was then crushed and heated at 200^{o} C for 2 hours to remove all residual carbon**.** Serpulid tubes may contain aragonite in addition to calcite, so the lower roasting temperature of 200º C was used instead of the traditional 400^{o} C (Glumac et al. 2004) to insure that any aragonite present would not be altered by the heat which would, in turn, alter the stable isotope readings. All stable isotope analysis was conducted at the University of Massachusetts Amherst Department of Geosciences Stable Isotope Laboratory.

X-Ray Diffraction

The use of X-ray diffraction (XRD) is documented in several paleo-studies (Herrmann 1973, Warren 1982) for crystal identification. Mineralogy can be significant in the identification of the origin of sediments. Samples taken for X-ray crystallography were cleaned and mounted on glass fibers. A GEMINI single crystal X-ray diffractometer set to 50 Ku and 40 mA was then used to identify the crystal shape and area of the large minerals present in the sample. The resulting readings were compared to known minerals.

Results

Radiocarbon Dating

Three AMS radiocarbon dates from Beta Analytical provided chronological control on the cores (Table 2.1). The lower two dates, at 149.5 cm and 174.5 cm, were inverted, however their age ranges overlapped. For the purpose of this study, dates for particular levels were interpolated by calculating a range using the upper and lower bounds of combinations of all three radiocarbon dates. (Figure 2.5)

Loss on Ignition and Core Logger:

Loss on ignition and the GeoTek core logger produced similar results as seen in the curves of figure 2.6. The GeoTek core logger's density and fractional porosity readings showed three sharp deviations from the average readings at 73–74 cm, 151 cm and 182–185 cm with little variability between the peaks. The magnetic susceptibility analysis only showed slight deviations from the mean core value throughout the core that fell within noise value ranges (Figure 2.6).

The LOI results were highly variable, but three sharp peaks are clear in the same intervals as identified by the core logger analysis (Figure 2.6). The uppermost spike at 76 cm shows a three standard deviation drop in carbonate from the core average, from 23% to 2.75% and a sharp increase in other material of over two standard deviations from the core average: 55.7% to 77.28%. The spike at 150.5 cm is characterized by a sharp drop in organic content and only a slight rise in carbonate. At 182.5 cm, there is another sharp drop in organic content from 21.19% to 4.6%, but both carbonates and other material fluctuate less then one standard deviation.

Sediment and Mineralogical Analysis.

Sediment and mineralogical analyses were run on samples from four regions of interest. Three regions were selected based on peaks or troughs in carbonates or other materials, or sharp drops in organics, as identified by LOI: 76 cm, 150.7 cm, and 182 cm. The fourth layer was identified visually as a layer of organic material at 175–176 cm (Figure 2.7). The 150.5, 182 and, 175–176 cm samples were classified using visual identification of sediments, while X-ray diffraction analysis (XRD) was used to identify the sample from 76 cm.

The abundant minerals in the sample taken from the 150.5 cm and 182 cm deposits are both the size and consistency of the beach sand found in the area, primarily carbonate and silicate (quartz/chert) beach sands. Also, mixed among the sand grains are micrometer scale fragments of coral (Figure 2.8). These findings indicate that these two deposits are composed predominantly of ocean sand, which typically contains little organics and a diverse range of sand grains and shell and coral fragments.

The sample from 76 cm contained small mineral fragments held together by a powdered mineral cement (Figure 2.9). Although the sample crystal was twinned, the XRD analysis was able to produce valid results, identifying the mineral as gypsum. Table 2.2 represents 59 out of 69 of the identified crystal peaks or 85.51%. The tabular, bladed crystal habit and characteristic twinning further identified the sample as selenite (Figure 2.10).

Biota

Two main biotic indicators were examined within the core: the distribution and stable isotope readings of serpulid tubes and the distribution and abundance of the forminfera *Ammonia beccarii*.

Serpulid tubes were present in four distinct bands within the core: 160–162.5 cm, 164.5–166 cm, 168.5–171 cm and 175–179.5 cm (Figure 2.11). Most of the serpulid tubes throughout the core, except for a 1 cm band at 175 cm, demonstrate an unusual vertical growth pattern (Figure 2.12). Additionally, many of the individual serpulids were attaching to, and growing on, other individuals (Figure 2.13). Stable isotope analysis of the serpulid tubes produced high $\delta\ ^{18}O$ values (Figure 2.14).

The common foraminifera *Ammonia beccarii* (Figure 2.15) are present between 151–178 cm (Figure 2.16). At ~154 , 161 and, 175 cm. *Ammonia beccarii* is primarily the only microfossil present.

Discussion

GeoTek core logger analysis of fractional porosity and density identified three major changes in the sediment properties at 74–77 cm, 151 cm, and 182–185 cm and confirmed what had been identified through visual inspection and loss on ignition. The loss on ignition analysis defined three layers exhibiting significant differences from the rest of the core, and provided enough data to classify distinct regions of interest at 75 cm, 150.75 cm, and 185 cm. The older Regions of Interest (ROI) at 150.75 cm and 181.5 cm both have significant drops in organic content and increases in the levels of carbonates. This is commonly associated with a massive influx of inorganic materials from hurricane overwash. Chronological examination of the core's sediments and biota provide evidence required to describe the environmental history of L. Alejandro and the surrounding area.

The ROI from 181.5–188 cm is composed of coarse sand and coral fragments and contained numerous shells and shell fragments, indicating that it may not be from an overwash deposit, but sand deposited when the lake was fully connected to the ocean. This deposit was located at the bottom of the profile, and the material below the profile, could be bedrock or additional consolidated sediments, which compounds the difficulty of identifying the origin of the 181.5–188 cm deposit. However, our analysis of biotic indicators and a distinct organic layer directly above this layer, indicate that the unconsolidated materials between 181 and 188 cm are from a period of time when the lake had a high level of interaction with the ocean.

The thin band of leafy organic content (1131±79 cal YBP) may have been deposited as storm debris when a major tropical storm event occurred (Liu and Fearn 1993). However, this layer may be due to the sharp increase in salinity that occurred as or after the lake became fully disconnected from the ocean. After all inlets between the lagoon and the ocean were closed, the lake salinity would be completely dependent on the total amount of fresh water input. As more or less fresh water flowed into the lake, the lake's salinity fluctuated accordingly. This increase in salinity could have shocked the surrounding mangrove vegetation. Due to the lake's proximity to locations with large mangrove populations (Bolay 1997) and the mangrove's upper threshold for salinity tolerance being 50% that of pure sea water (Ball and Pidsley 1995, Ball 1998), it is plausible that after taking root in this newly formed basin, the mangroves suffered a catastrophic die back. Stable isotope values from the serpulid analysis (Figure 2.14) also support this idea, as there are lower $\delta^{18}O$ values below this layer, and significantly higher values above this interval.

Ammonia beccarii is a commonly found foraminifera associated with brackish environments. The unique characteristic of the *Ammonia beccarii* deposits within this core is the absence and/or minimal presence of any other microbiota near the bottom of the core (168–175 cm). The distribution pattern of *Ammonia beccarii* within the core is a commonly observed pattern under specific circumstances, typically upper tidal conditions (Haslett 2001). We interpret this interval (1097±73 and 1131±79 cal YBP) to represent a period of time when a variety of environmental conditions around the lagoon were fluctuating. Salinity, lake-ocean conductivity, and the mean high tide level most likely fluctuated in response to the formation of the lake.

Both the distribution and growth of serpulid tubes within the core, as well as the stable isotope data gathered from the tubes, were important to interpretation of lake formation. Although it was impossible to identify the individual species of serpulid from the 70 recent genera and 500 nominal species using only their calcareous tubes, the distributions of tubes provide insight to the lake history (Rouse and Pleijel 2001; Ferreo et al. 2005). In general, the distribution and growth patterns of the serpulids within the core both provides insight and poses difficult questions, particularly as the vertical growth pattern of the serpulid tubes in L. Alejandro is highly unusual and undocumented in any literature. Also, the loose sediment substrate in which they are growing is also highly unusual. Serpulids generally do not prefer this type of stratum; most species are highly particular and will only attach themselves to their preferred stratum (Silva 1962). The serpulids in L. Alejandro were growing in organic rich-mud; in most settings serpulid larva attach to and grow and congregate on coral or large substrate (such as shells and rocks) in the ocean (Silva 1962; Marsden and Meeuwig 1990). Generally a larva attaches itself to a small shell or wood fragment, and then subsequent larvae attach themselves to the original serpulid tube, which is highly evident within the core (Figure 2.13).

There are many possible reasons for the vertical growth pattern expressed in this lake. The most plausible reason concerns the fast rate of sedimentation within the lake. Serpulids are common to water bodies where there is little or the open ocean; their growth typically forms an interwoven mat, which is suggested by the growth at 175 cm. In areas with relatively high sedimentation, such as the L. Alejandro profile, they are forced to grow vertically in order to prevent burial. The vertical growth of serpulids observed in L. Alejandro leads us to speculate that the lake would have been at least partially open to the ocean to provide larva which could take hold, while at the same time protected enough to prevent tidal activity from removing or depositing large amounts of sediment.

The four distinct serpulid layers are functions of three different events. The 1 cm thick layer of organics at 175–176 cm abruptly stopped the growth of serpulids, most likely suffocating them. Serpulids reappear at 171 cm, possibly due to a slight slowing of the sedimentation rate or merely time lag in the arrival of larva to the lake. Their seemingly abrupt die off at 168 cm (1097±73 cal YBP) coincides with a distinct layer of shell that is apparent in the X-radiograph (Figure 2.17). Most of the shells are *Anonalocardia brasiliana*, a brackish bivalve common to the Caribbean. The deposition of this shell layer may have occurred during a hurricane event (Liu 2000), or could be due to a change in lake salinity creating a toxic environment for *A. brasiliana* and possibly other biota (Figure 2.17).

The serpulids reappear at 166 cm possibly for the same reasons already mentioned. At 164.5 cm, the serpulids experienced a die back, but not a die off indicated by continued but declining presence. This may relate to a slight increase in the sedimentation rate, which selected for only the fastest growing of the serpulid individuals. At 162.5 cm there is an increase in the population possibly due to a slight decrease in the sedimentation rate. Finally, at 160 cm (1060±66 cal YBP), all significant serpulid populations disappear, probably due to a combination of factors: an increase in the sedimentation rate and a final closing off of the lake, thereby eliminating the possibility for larvae to reestablish themselves. It is also possible that salinity changes and/or toxic soil properties may be attributed to the die off of serpulids. However, these scenarios are unlikely because there is not significant change in the sediment color or makeup that might represent the introduction of new sediments that would have been harmful to the serpulids. Further, the staple isotope analysis revealed that the lake was hypersaline throughout that distribution of serpulids.

The stable isotope analysis on the serpulid tubes further supports the theory that between 1060±66 cal YBP and 1158±85 cal YBP the lake was closing off from the ocean. Serpulids form tubes with δ ^{18}O values that closely match that of ambient water, and thus can provide a detailed account of water salinity (Videtich 1986). Oxygen isotope values decrease at a rate of 0.3–0.6 for every 1 unit decrease in salinity (Greer and Stewart 2006), so the high values from the L. Alejandro serpulids represent a time with increased salinity within the lake. Although lowering of water temperature can also increase the δ ^{18}O values, given the low latitude and shallow depth of the lake it is unlikely that the lake could have cooled to the necessary temperature to cause the observed increases (Leder et al. 1996). Also, there is more variation in δ ^{18}O in restricted basins. It is impossible to definitively calculate the salinity levels and only generalizations can be made (Greer and Stewart 2006). L. Alejandro serpulid δ ^{18}O values are comparatively much higher than serpulid δ ^{18}O values from samples gathered higher in the valley in terrestrial locations that are thought to be representative of historical marine environments (Glumac et al. 2004, Guerard 2001, Berrios 2002, Winsor 2006), indications that L. Alejandro was hypersaline.

The relationship of δ ^{18}O values between samples also provides insight into the salinity of the lake over time. The serpulids from 167 and 176.8 cm have lower δ ^{18}O values (Figure 2.14) than suspected marine environment values (Glumac et al. 2004), and may represent a period of greater interaction between the lake and the ocean, or could represent a period of increased rain that lowered salinity of the lake. This second hypothesis also helps to explain the layer of organics at 175–176 cm. Higher than average rainfall over an extended period would have lead to decreased salinity in the lake, making the previously hypersaline shoreline area more conducive to vegetation growth. As rainfall declined the lake salinity would increased, as indicated by the δ ^{18}O values at 175.5 cm. The increased salinity would have created an inhospitable environment for some plants, causing die back. As freshwater input was cut off to the lake, very little sediment would be received via alluvial transportation, and the only contribution to the sediment record would have been the organic content contributed by dying mangrove vegetation.

Additional coral fragments were found in the 150.5–152.5 cm, indicating a similar sediment source as the 181.5–188 cm interval. However, even though the source of these deposits are the same, the mechanism that deposited them is likely very different. The deposit at 150.5–152.5 cm (1022 ± 60 cal YBP) is made up of fine uniform sand grains and is surrounded by highly organic sediments. These characteristics make it unlikely that this deposit was transported to the lake through a canal or tidal channel due to the uniform limestone ridge that separates the lagoon from the ocean. A hurricane landfall, which formed an overwash fan would be the most logical explanation of its origin (Liu 2000). This deposit most likely represents a Category 3 hurricane or stronger (Liu and Fearn 1993). No storms greater than Category 1 have struck within 20 miles of the lake during recorded history, explaining the absence of deposits during recent time.

The most distinctive sedimentological event recorded in the core took place at 620 ± 60 cal YBP and is represented by a 2.5 cm deposit of selenite (gypsum) from 74.5 to 77 cm. Unlike the other two ROIs identified by the LOI, this region does not have a significantly high percentage of carbonates, and is primarily silica and other minerals. The distinctive layer of gypsum at this interval is significant because it records one event in the lake and also expresses in formation about the environmental conditions around the lake and in the Sierra de Martín Garcías. Perhaps more importantly, the gypsum layer also provides insight to the climatic conditions of the lake and mountains during the entire 1200 year time line recorded by the core.

Gypsum normally precipitates out of standard ocean water at a density of 1.115 g/cm^3 (Lepeshkov and Bodaleva 1952); however in the Caribbean, which is approximately 10% more concentrated then standard seawater, gypsum precipitation will occur at a water density of only 1.0897 g/cm^3 (Baseggio 1974). In order to reach that density, about 80% of the water must evaporate from normal sea water due to the ability of calcium sulfate to remain in solution until a high level of supersaturation is met (Sonnenfeld 1984). In order to increase salinity, the lake may not need to dry out or even decrease its water level significantly, which is common in lakes in the Persian Gulf region (Wells 1962; Curtis et al. 1963). This is achieved when evaporation is taking place concurrently with a replacement of saline water into a closed system.

It is also important to note that this thin deposit of selenite is the only evaporite present at this interval, and it is the only evaporite deposit present in the core, which directly supports the theory that the lake did not dry out. If lake salinity increased to the eutonic point (the point at which all evaporites will precipitate out: about three molecules per ion), then all evaporates would have precipitated out, and layers of halite, and other evaporites, such as sylvite or bischofite, would have been present within the core (Handford 1988; Sonnenfeld 1984). The absence of these other evaporites indicates that within the last 1200 years the lake has not experienced a density greater than 1.2185 g/cm^3, the density of Caribbean sea water at which halite precipitates (Baseggio 1974).

It is evident from visual inspection of the site that the lake was once larger than it was at the time of sampling, as the northwest shore of the lake has exposed lake bed. The drying of the lake could be due to seasonal fluctuation, or could be orchestrated by the owners of the active salt mining operation currently conducted on the northeast shore. It is possible that the dried out areas of the lake were artificially created by the mining company in their pursuit of salt, and therefore would have no relevance to the interpretation of natural forces acting on the lake.

Based on the 80% evaporation of salt water that must occur before gypsum precipitates as set forth in Sonnenfeld (1984), it can be inferred that because L. Alejandro is only ~200 cm in depth, it is unlikely that evaporation was the only mechanism for the lake’s sharp increase in density and the precipitation of gypsum.

A scenario in which evaporation (without additional seawater input) takes place would require the 200 cm deep lake to fall to a depth of 40 cm (80% evaporation), and then not continue to dry out the additional 20–30 cm to reach the eutonic point, the point at which all salts precipitate. While possible, it is unlikely for the lake to evaporate over 160 cm of water depth and then not completely dry out, due to the arid climate. The more likely scenario is that lake density increased while maintaining a relatively constant, or at least not significantly reduced, lake volume. Stability in lake levels is most likely attributed to a steady infusion of seawater through the limestone ridge and lake floor. Because the lake is receiving salt water though infusion, and not a direct connection, there is little possibility for the lake system to be flushed. Within the lake, the salt water mixes with a continuous or semicontinuous flow of fresh water from streams originating in the Sierra de Martín Garcías keeping the salinity relatively stable through time (Figure 2.18).

The most likely cause for the distinct layer of gypsum is a period of drought in the Sierra de Martín Garcías. During a long-term drought, the fresh water inputs to the lake could cease entirely. Without a source of fresh water, the evaporating lake would only be replenished by seawater infusion. Over time, the salinity of the lake would increase. Due to the slow rate of salinity increase though the infusion/evaporation process, it is likely that the drought was not long enough to cause lake levels to decline sufficiently to cause other evaporites to precipitate. Once rain returned to the Sierra de Martín Garcías and streams again flowed into L. Alejandro, lake salinity would have decreased and the precipitation of gypsum would have ceased. Several studies provide detailed accounts of dry periods that occurred between 930 to 10,000 cal YBP, with the past 1000 years generally referred to as being drier (Hodell et al. 1991; Islebe and Sanchez 2002; Curtis et al. 1996). Other possible sources of the gypsum, such as the Ochsenius-Krull model (Sonnenfeld 1984), which details the creation of gypsum and other evaporites behind high sand barriers that restrict the ability of normal ocean circulations to flush the system, thereby leading to hypersaline conditions, can be dismissed due to the absence of other evaporites such as halite, or any K-Mg salts from the sediment record. Also, because of the limestone barrier, sea water from waves or transgression would be impeded, not allowing for the transportation of sediment into the lake. It is also possible that lake density did increase enough for halite precipitation to occur, but the highly soluble halite could have dissolved when salinity decreased leaving no permanent record in the sediment profile. The lack of evaporites other than gypsum makes this scenario seem unlikely.

Although a detailed history was gathered from this core site through multiple proxies detailed above, the GeoTek core logger analyses conducted did not add much additional detail to the study. Particularly, while magnetic susceptibility testing conducted on sediments from Lake Miragoane, Haiti (Curtis and Hodell 1993) showed significant fluctuations, the magnetic susceptibility tests conducted in this study showed only little variability in diamagnetic material. Magnetic susceptibility is a valuable proxy because an increase in ferri-magnetic minerals can often be a reflection of increased erosion that may be linked to climate change or human activities (Maher 1998). We expected that these tests would reveal fluctuations that would go undetected by other sampling techniques and provide some details into the environmental history of the lake. However, the core from Laguna Alejandro showed no significant fluctuations in magnetic susceptibility.

Conclusion

This study provides a starting point for further paleoenvironmental studies both within this lake and within the region by providing insight into key local and regional events, and providing pieces to the larger puzzle of oscillations in climate and hurricane history. Evidence from the L. Alejandro sediment core reveals a substantial drought in the Sierra de Martín Garcías around 620±60 cal YBP. A deposit of ocean sands reveals that a powerful hurricane struck the coast in this area around 1022±60 cal YBP. The distribution patterns of *Ammonia beccarii* indicate that the lake was becoming autonomous between 1097±73 and 1131±79 cal YBP, and stable isotopes from serpulids indicate that lake salinity levels were also increasing at this time. A layer of shells at 1130±40 cal YBP may indicate either a storm event or may be a result of increased salinity within the lagoon. Low stable isotope values below a layer of organics at 1158±85 cal YBP and high stable isotope values above this layer may indicate a period of heavier then average rains in the years before 1158±85 cal YBP at which time we are seeing a die back of vegetation do to an increase in salinity. At 1163±85 cal YBP large sand grains and shell fragments indicate the lagoon did not exist (Figure 2.19). Because there have been no in-depth neotectonic studies in the region, the specific mechanism that created the lake cannot be identified, but slight uplift is a possibility.

The Laguna Alejandro sediment record provided a detailed history of ecosystem shifts as the lake transitioned from being open to the ocean to developing into an autonomous system and provided evidence of one or more major hurricane landfalls over the past millennium.

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Chapter 2 Figures

Figure 2.1: Location of L. Alejandro (informally named by researchers) in the Dominican Republic on Landsat 7 imagery. (18.31^o N 71.03^o W)

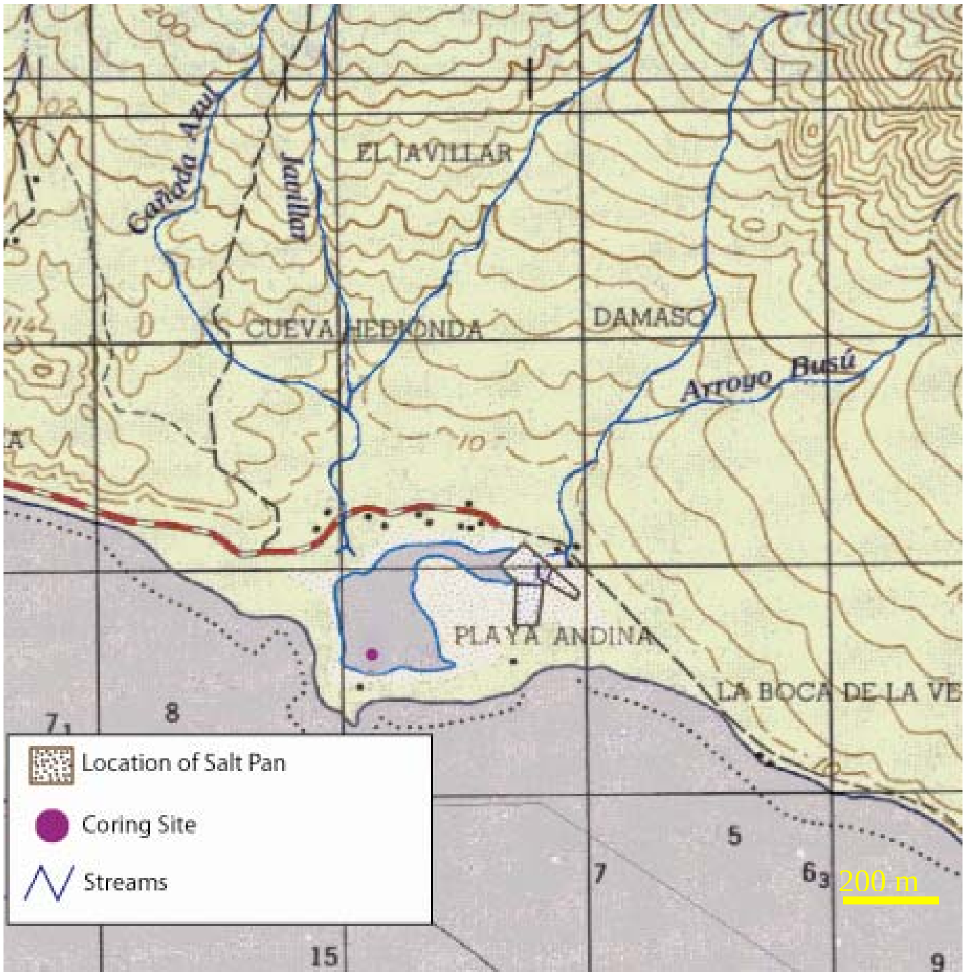

Figure 2.2: A section of the 1:50000 Barahona quadrangle showing L. Alejandro (18.31^{o} N 71.03^{o} W) and surrounding features. Map contour interval is 20 m and each grid square is 1 km^{2}.

Figure 2.3: Line spectral images (right) of the two sequential cores taken from L. Alejandro alongside the X-radiography (left) for each core. A. is 0–100 cm, B. is 100–185 cm.

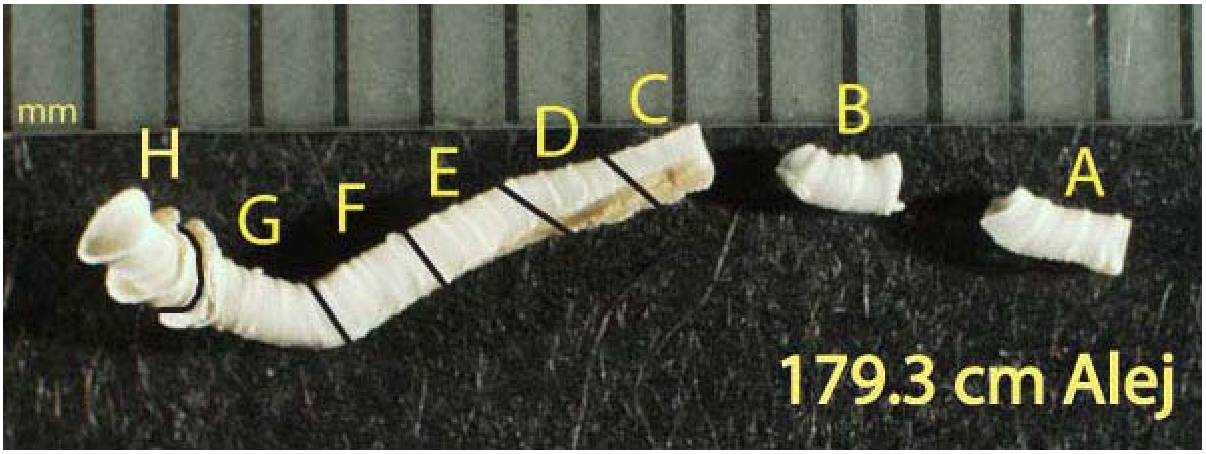

Figure 2.4: Example of serpulid divided into subsections for stable isotope analysis.

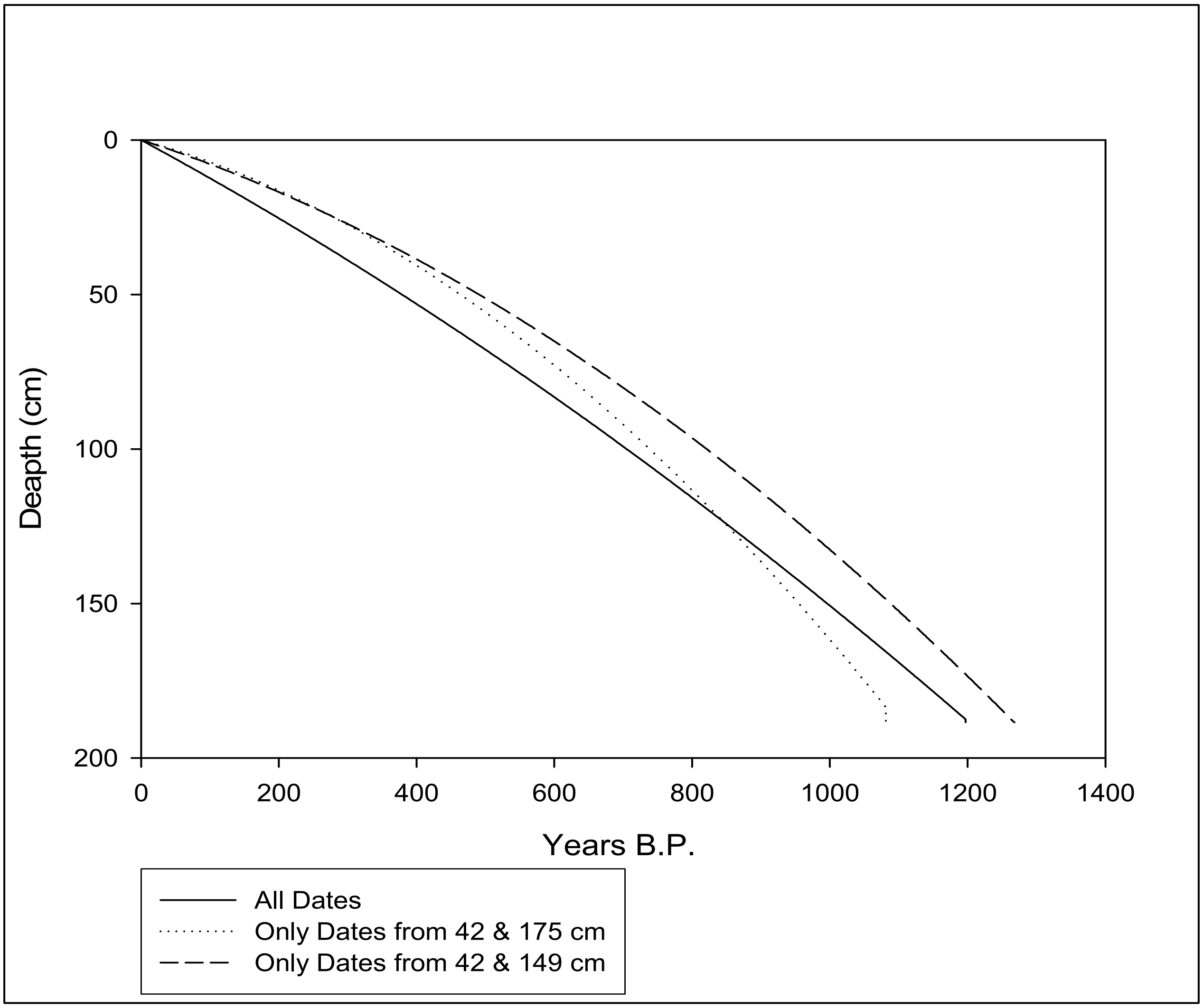

Figure 2.5: Represents the three polynomial trend lines created using all dates obtained, only dates from 42 cm and 174 cm, and 42 cm and 149 cm. These data were used to calculate relative ages of events represented within the core.

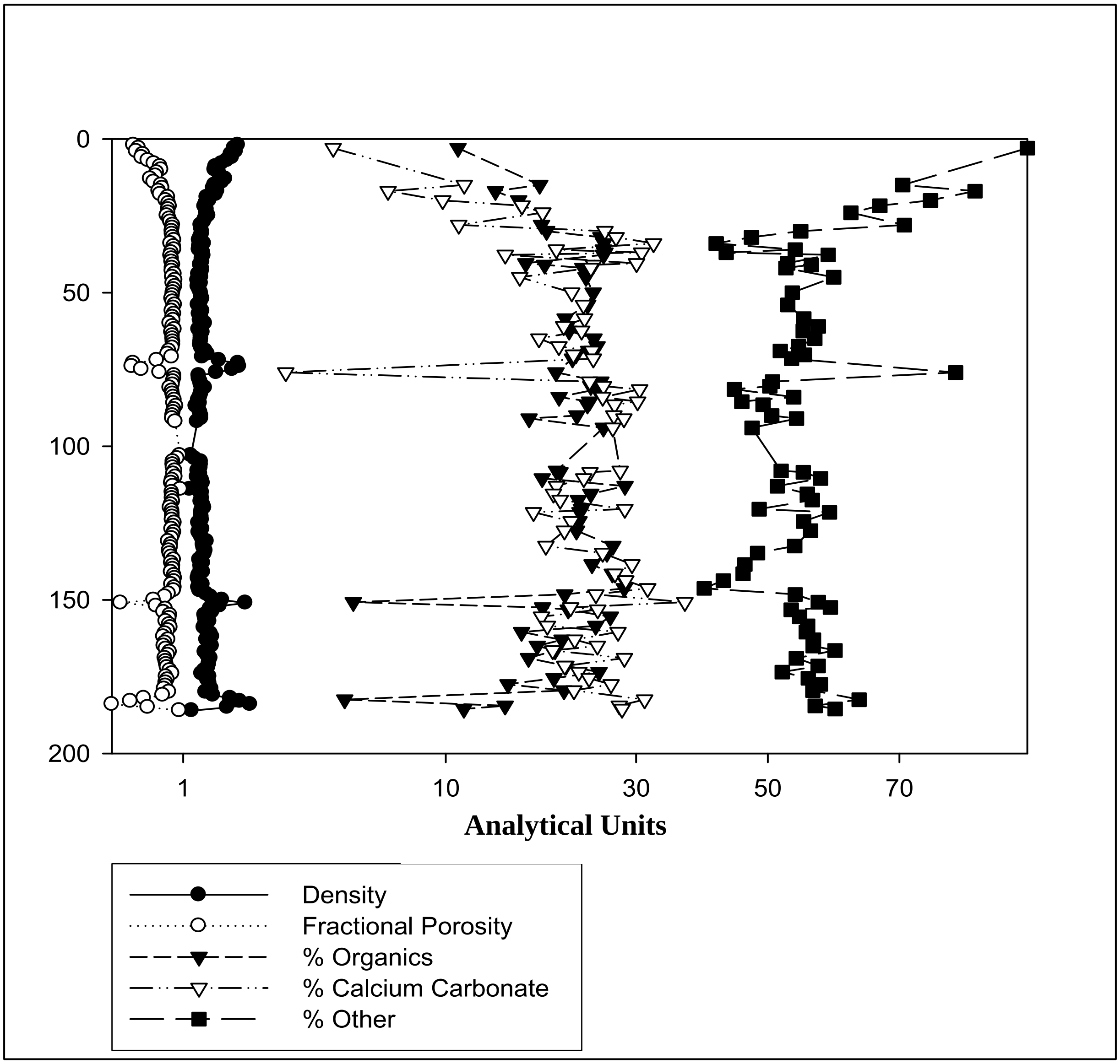

Figure 2.6. Loss on ignition, density and, fractional porosity data from L. Alejandro.

Figure 2.7. Organic deposit at 175–176 cm (dark areas).

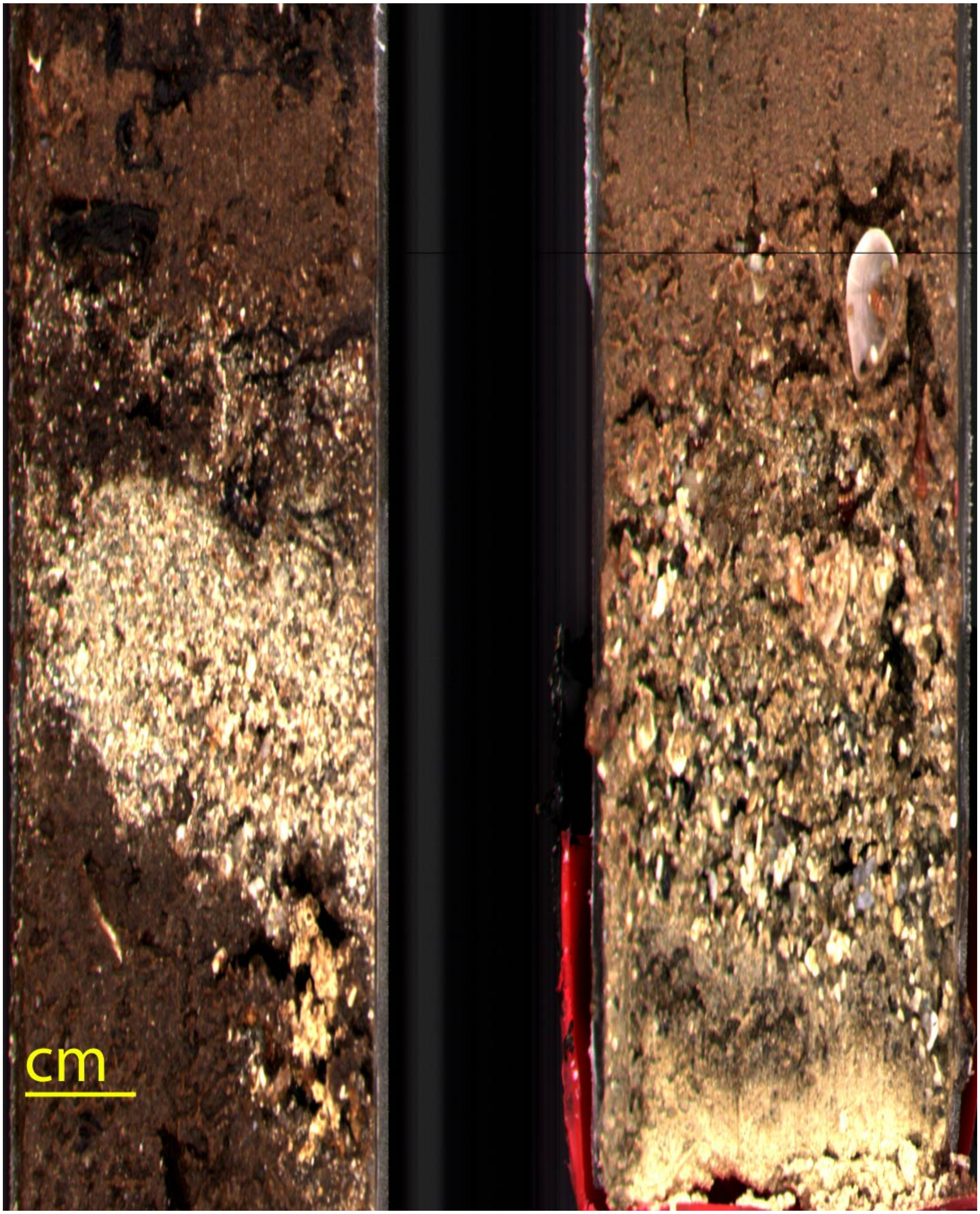

Figure 2.8. Sand deposits at 150.5 cm and 182 cm (light colored areas).

Figure 2.9. Gypsum and powder cement from 74.5–77 cm.

Figure 2.10 Samples of a selenite gypsum crystal.

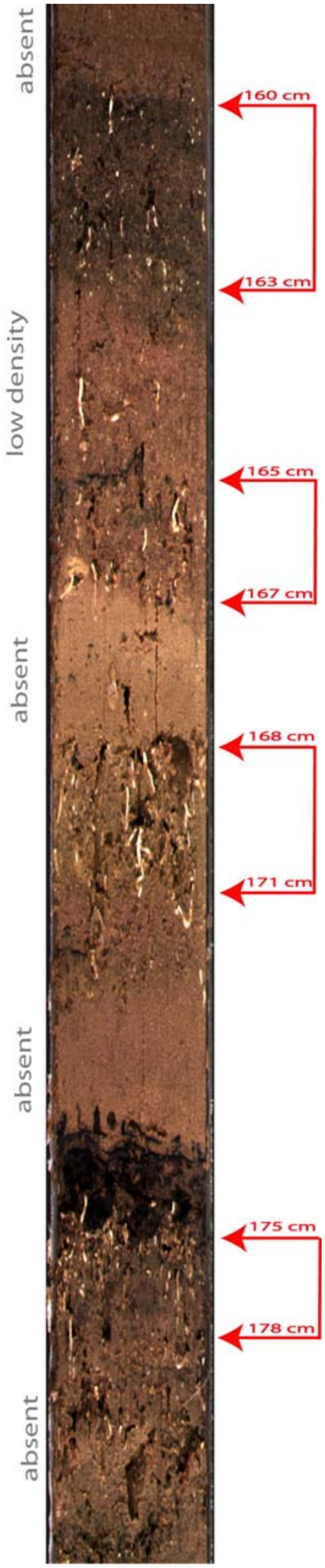

Figure 2.11. Serpulid growth within the core.

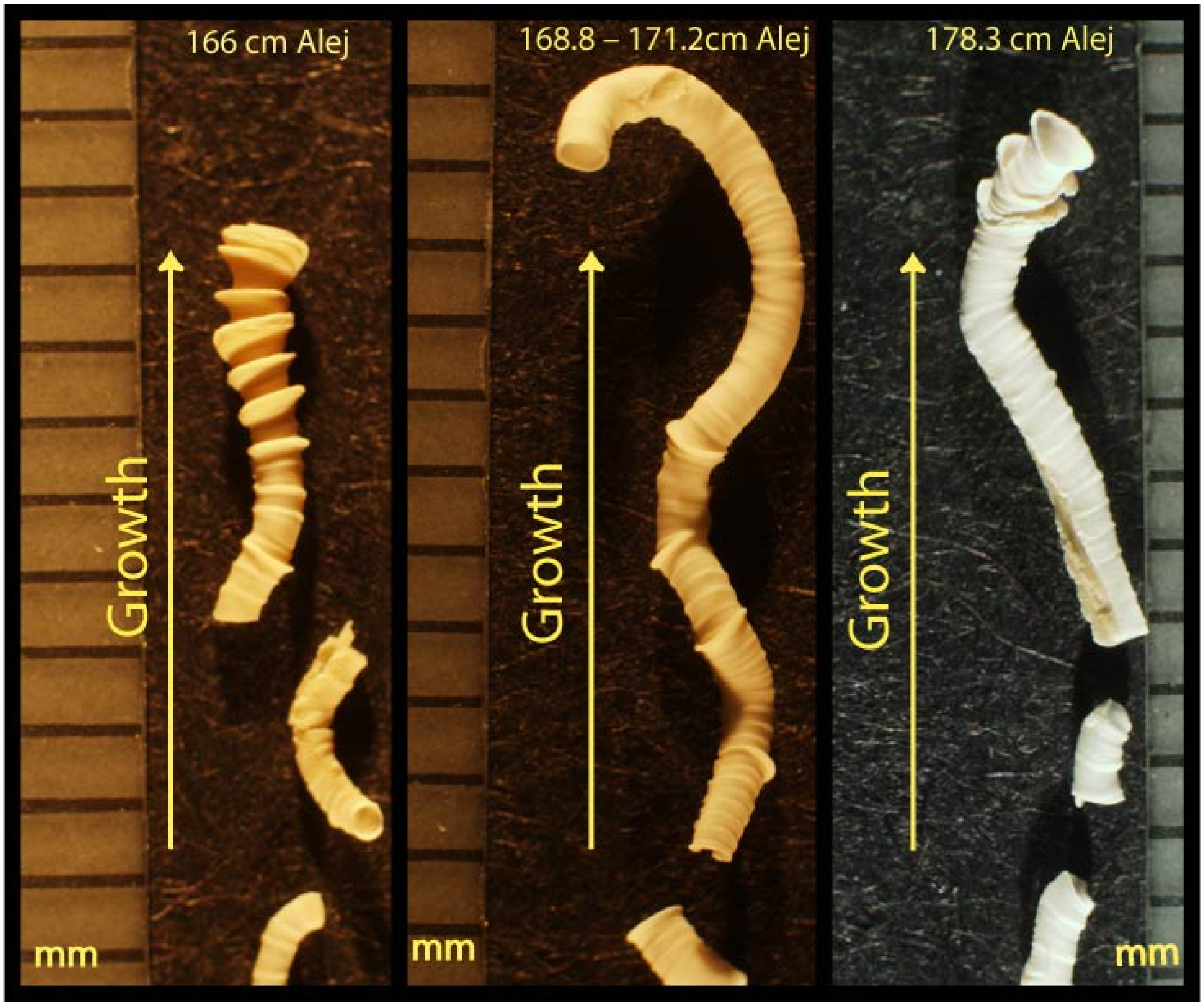

Figure 2.12. Examples of vertical growth of serpulids within L. Alejandro sediment core.

Figure 2.13. Serpulids growing off other serpulid tubes in L. Alejandro sediment core.

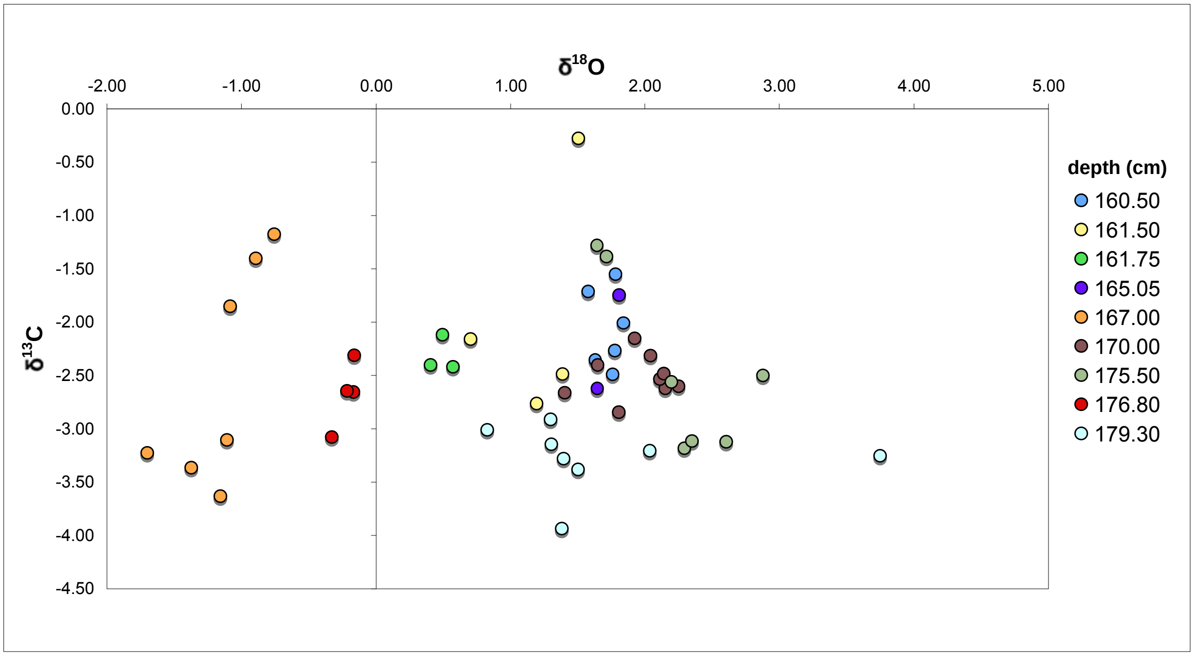

Figure 2.14: Stable isotope analysis of serpulid tubes in L. Alejandro. Each point represents the ^{13}C and ^{18}O values for a given sample.

Figure 2.15. *Ammonia beccarii*

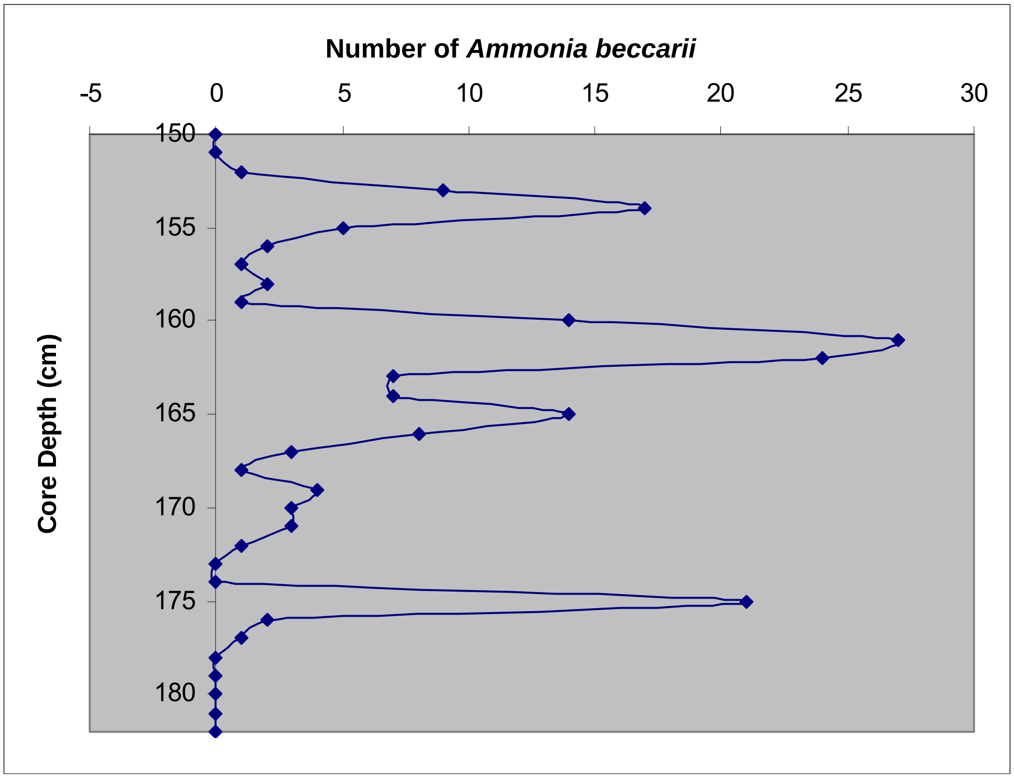

Figure 2.16: Total counts of *Ammonia beccarii* in 0.5 gm samples within the lower most 35 cm 150–185 cm).

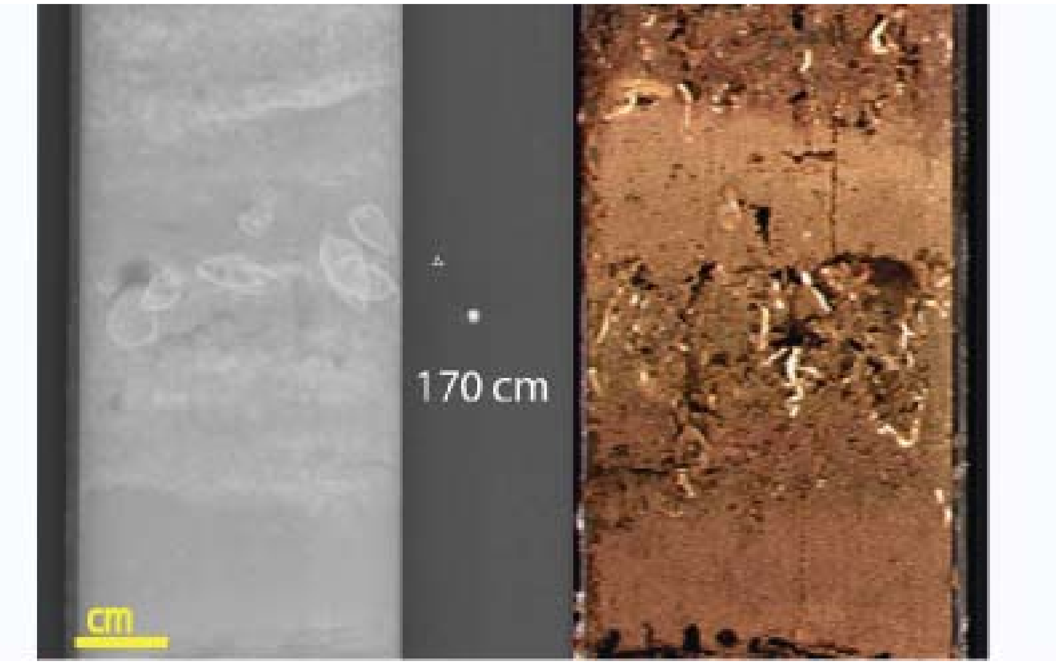

Figure 2.17. Distinct layer of shell at 168 cm in the L. Alejandro core. Left side is X-radiography, right side is line spectral image.

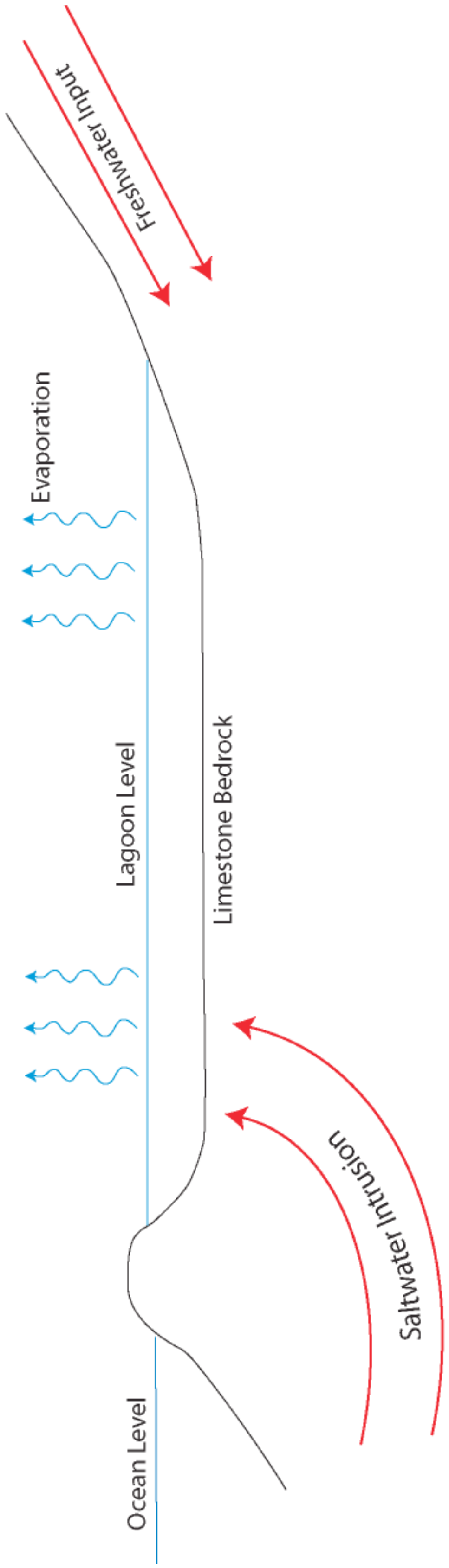

Figure 2.18. Diagram of water balance into L. Alejandro.

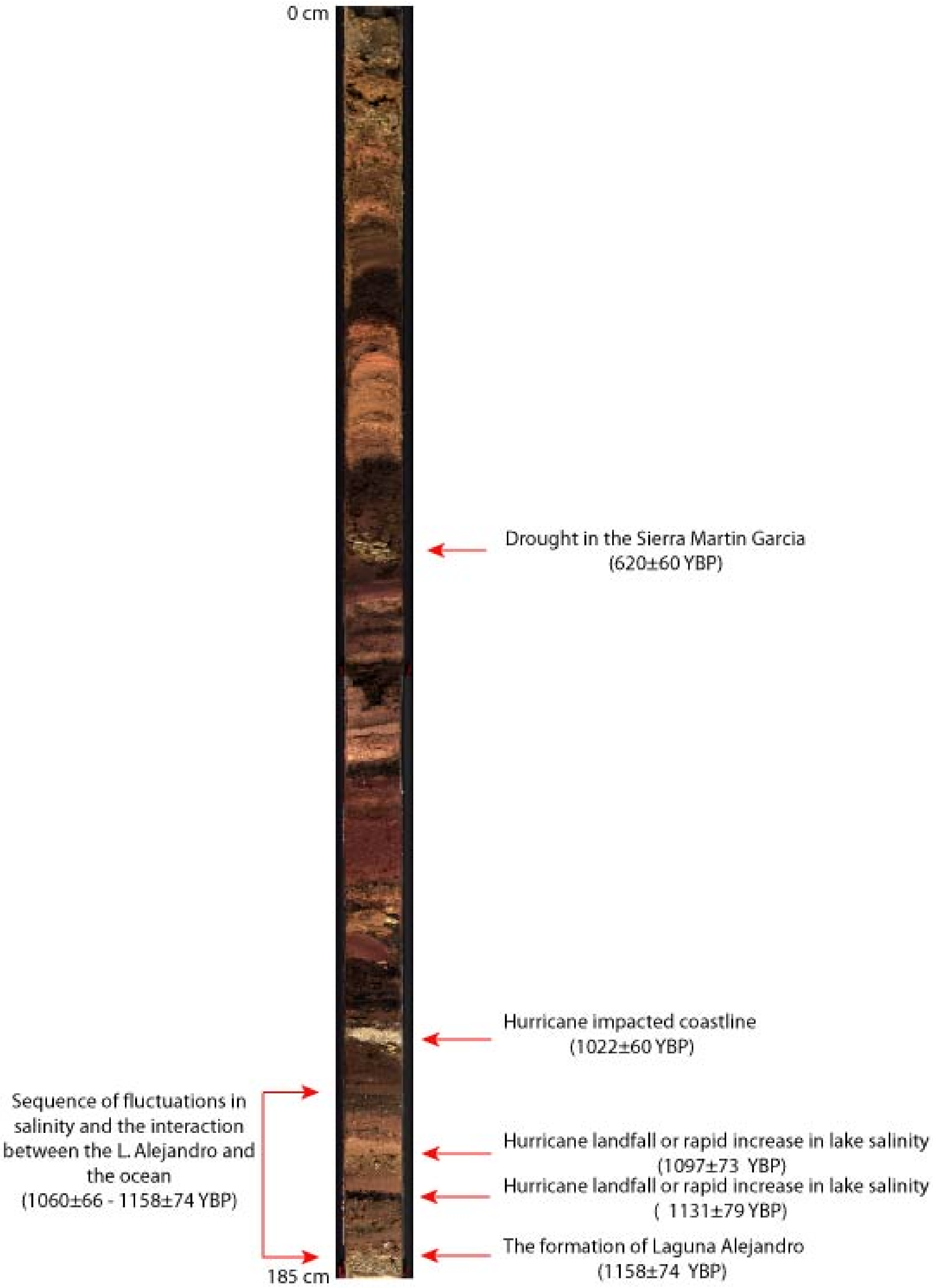

Figure 2.19. Line spectral image of the core with notation of key environmental events.

Chapter 2 Tables

Table 2.1 Results of radiocarbon analyses performed at Beta Analytic. Inc.

Laboratory Code	Material Dated	Depth(Cm)	Conventional radiocarbon age (14C yr BP)	Calibrated age ± 2σ (yr BP)
Beta - 218661	Plant	42–43	310 +/- 40 BP	478 - 297
Beta - 218662	Wood	149.5	1070 +/- 40 BP	1058 - 927
Beta - 218663	Wood	175–175	1000 +/- 40 BP	975 - 795

Table 2.2. Results of X-ray diffraction analysis of sample taken from 76 cm depth in L. Alejandro sediment core.

Volume	Edges	Angle
487.7(18)	6.298(12)	114.1(2)
	15.19(2)	
	5.689(7)	