3000 Years of Coastal Evolution in Grand Pré

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Abstract

The community of Grand Pré, Nova Scotia in accordance with Parks Canada is in the process of completing a proposal to make Grand Pré dyke lands a world UNESCO heritage site. Acadian settlers 330 years ago settled in Grand Pré to transform an area of salt marsh and mud flat into farmland. Prior to the arrival of the Acadians the salt marsh and mud flats were constantly transforming due to the tidal range and Bay of Fundy currents. To understand the complex environment core samples were collected and a comprehensive study was completed on the Foraminifera zonations to reconstruct the past environment. *Trochammina inflata* and Tiphotrocha *comprimata* dominate the high to middle marsh and *Elphidium williamsoni and Haynesina* dominate the mud flat environments. Correlation of these environments has revealed past transgressive and regressive cycles and information on the effects of anthropogenic changes to the landscape. Using carbon-14 age dating it was determined that the sediments penetrated has a 2700 years old contact between high marsh and mudflat. Using this information scenario models were created and reconstruction of the coastland at Grand Pré was possible.

Key Words: Grand Pré, Minas Basin, Marsh, Mudflat, *Trochammina inflata*, *Elphidium advenum*

Elphidium williansoni , *Tiphotrocha comprimata*

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1.0 Introduction

Grand Pré is located in the Minas Basin, Nova Scotia where some of the world's largest tides occur. The objective of this study was to understand the relationship of marsh foraminifer compared to marsh elevation above mean sea level. Using the foraminifer data collected from cores facies changes and marsh elevations were determined. Therefore, by interpreting the information collected, the relocation of former sea levels and coastlines is possible. Other studies completed in the Minas Basin act as analog models and contribute information used to understand the data from Grand Pré. One key focus of this study was work completed by Smith et, al. (1984) which contributed five analog model using marsh foraminifera and their application to sea-level determination. Though is not directly related to the study at Grand Pré it provides marsh foraminifera facies indicators plus tidal and sea level information in the Bay of Fundy and Minas Basin. One of the major influence on the Grand Pré landscape was the arrival of French Acadians in 1760. The French Acadians, whose knowledge of dyke construction dramatically altered the Nova Scotia shoreline in the Grand Pré region, converted what was once considered useless marshland into productive agricultural land. In the Grand Pré Region a series of dykes were constructed connecting the east and west tips of Long Island to the mainland. This resulted in the eventual transformation of the land in between Long Island and Mainland Nova Scotia into farmland. This outlines the last component of the evolving coastline at Grand Pré which is only one of five coastal models completed in this study.

Although numerical models of marshes have been completed previously with considerable advances, the relative speed and frequency of geomorphological and sedimentological variability remains high due to the variations over time (Davidson-Arnott et al. 2002). The ultimate goal in this study is to provide evidence that foraminifera zonition accompany with relative sea-level rise and tidal regime data can provide sufficient information to build a coastal evolution scenario modal of Grand Pré.

1.1 STUDY AREA

1.1.1 Geographic Setting

Grand Pré is a small town located on the southwestern edge of Nova Scotia's Minas Basin (Fig. 1.1). The area of interest is the stretch which lies between Grand Pré and Long Island and has an area of roughly 30 km^2 (Fig. 1.2). Its primary land use is now agriculture, but before the Acadians settled this region in 1680, this area was entirely salt marsh and mudflat. The former marshes in this area developed a part of the estuarine system, which drains into the Minas Basin. The Cornwallis River empties into the basin to the west of Grand Pré and the Gaspereau River to the east.

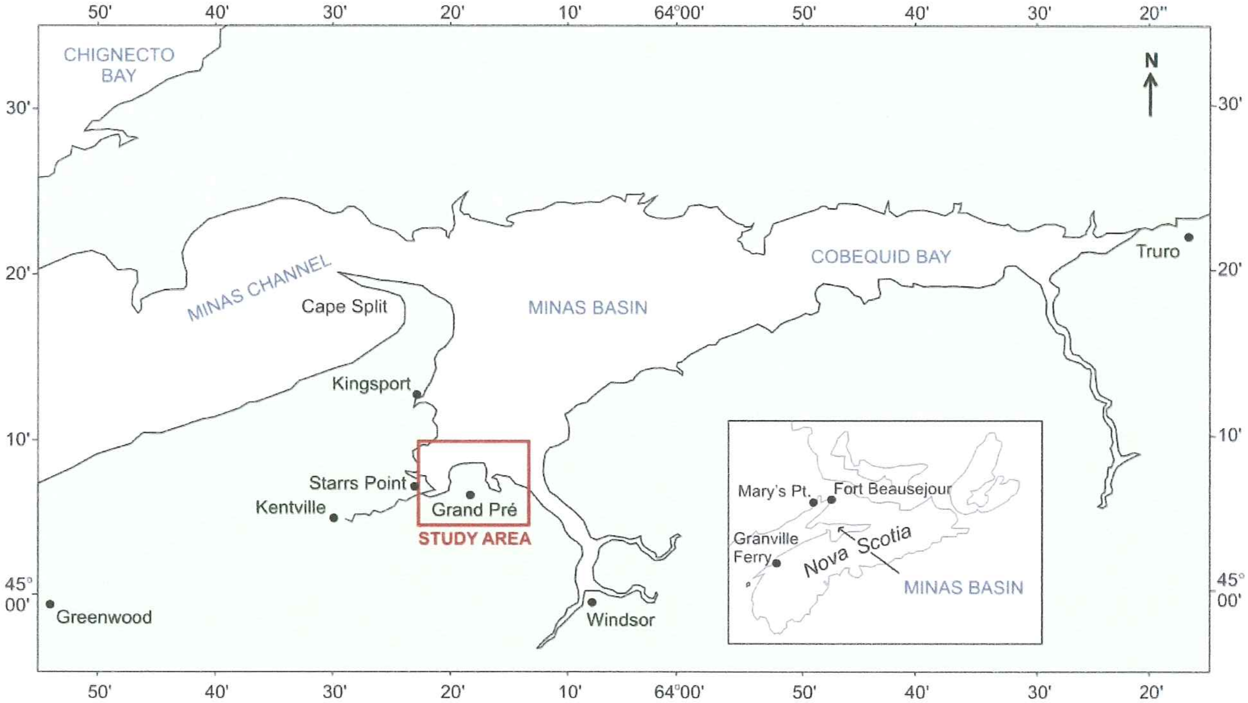


Figure 1.1: Map of the Minas Basin and surrounding area illustrating the location of the Grand Pré study area (modified from Amos and Mosher, 1985).

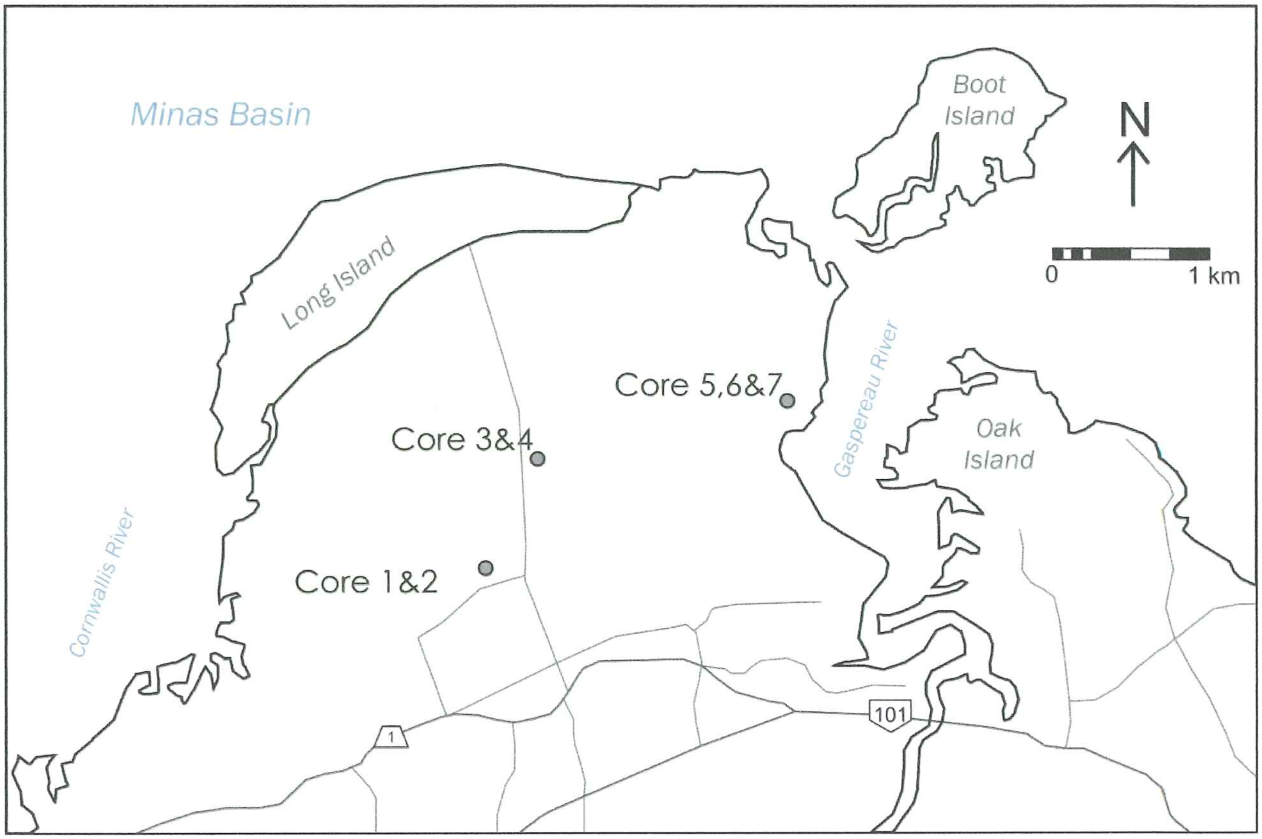


Figure1.2: Map of Grand Pré, Nova Scotia illustrating the location of cores obtained and sampled during this study.

1.1.2 Geologic Setting

Grand Pré is underlain by the Triassic Wolfville Formation which consists of interbedded conglomerate, sandstone, siltstones and mudstones (Trescott, 1968) (Fig. 1.3). In this region of Nova Scotia the Wolfville Formation was deposited unconformably on a basement of Cambrian-Ordovician rocks of the Meguma Group and the Devonian-Carboniferous rocks of the Horton Group as alluvial fans and fluvial deposits in the Late Triassic (Trescott, 1968). It was subsequently buried by the Blomidon Formation, which is predominately composed of siltstones and claystones with minor interbedded sandstones (Trescott, 1968). The Wolfville and Blomidon Formations were in turn overlain by the North Mountain Formation, a series of basalt flows (Trescott, 1968).

`The Fundy Basin is a rift basin that began to form in the early Mesozoic when the supercontinent Pangaea began to break apart (Withjack et. al, 1995). Upland sediments were then deposited in the basin during different phases of rifting which formed the rocks of the Wolfville and Blomidon Formations. Today these rocks are the primary sediment sources for the Quaternary marshland and tidal flat deposits in the Bay of Fundy. To the north and south of the Grand Pré dykeland the surficial geology consists of littoral and prelittoral sediments glacial till deposits and the dykeland itself is intertidal sediments (Rivard, et. al, 2007) The soils in the study area are from the Acadia series and consist of friable to firm, fine loamy, marine sediments (Freedman et al., 2001).

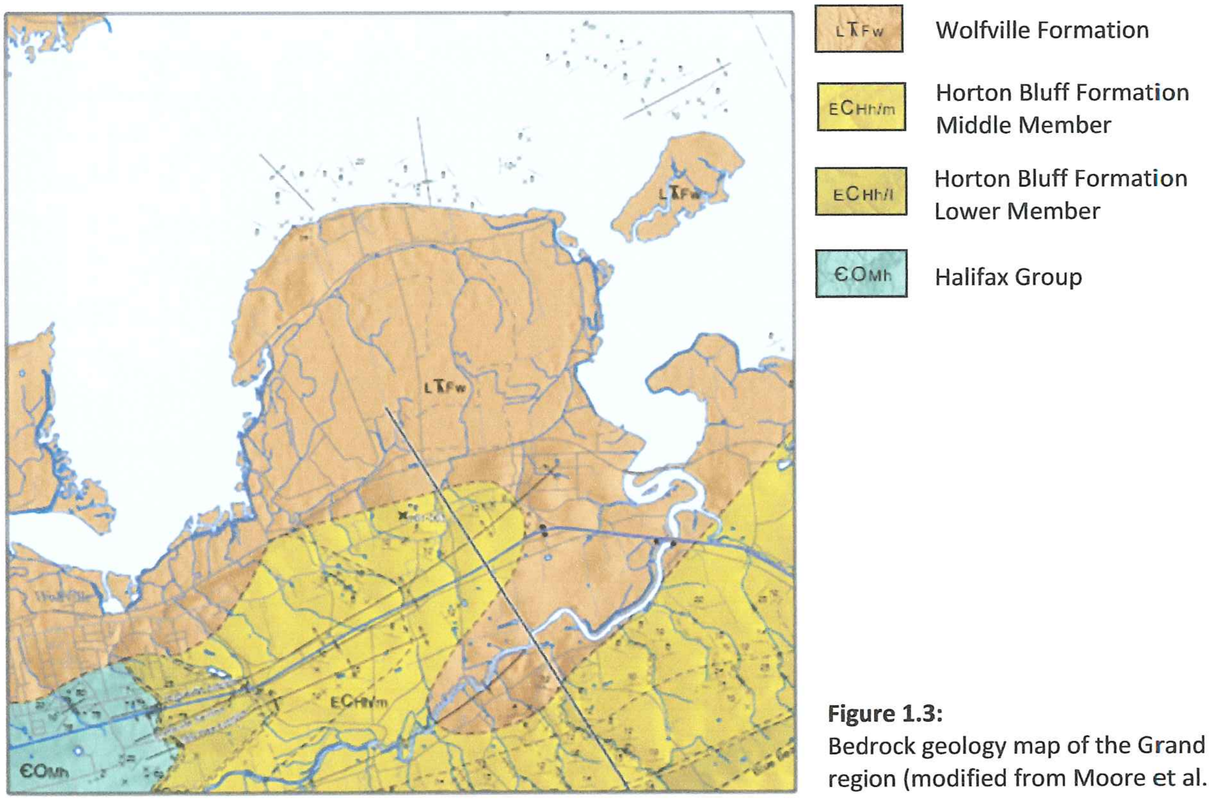


Figure 1.3:
Bedrock geology map of the Grand Pré region (modified from Moore et al. 2000).

1.2 MINAS BASIN

1.2.1 Minas Basin

The Minas Basin is a semi-enclosed embayment situated at the head of the Bay of Fundy connected through the Minas Channel. The Basin is sub-divided into several distinct geographic regions, the Minas Basin, Cobeqiud Bay and the Minas Channel (Amos, 1978). The Minas Basin has a suspended sediment concentration varing from 50 mg/L over the mudflats to more than 1 g/L in the upper part of the marsh (Amos et al., 1988). The change in greater accumulation is due to higher grasses in the marsh which removes the sediment from suspension whereas the mudflat creates lower amounts of friction and less accumulation occurs. The salinity at the entrances of the Cornwallis River adjacent to Grand Pré is generally more than 25 mg/L which is ideal for biological activity (Piccolo, 1993).

1.2.2 Fundy Tides

The Bay of Fundy is home to the largest tides in the world with amplitudes as high as 16 m. The Minas Basin experiences semi-diurnal tides, meaning there are 2 high and 2 lows tides per day. This means that it will only take 6 hours for water levels to rise from low tide to high tide. The ocean's tide has an average of a 2 metre range which is amplified throughout the Bay of Fundy due to the geometry of the basin, with the largest tide found in the upper Bay of Fundy (Scott and Greenberg, 1983). The amplification factor at the edge of the continental shelf to the coast generally ranges from 2.5 to 3 meters (Scott and Greenberg 1983). The central part of the Fundy basin has six times the greater tide than at the shelf edge. At the head of the bay the amplification increases to 10 meters in Chignecto Bay and 12 meters in the Minas Basin (Scott, 1983).

It was important for the Acadians to understand the tides before the construction of the dykes. This relationship was vital to the success of the dykes and in only 75 years the Acadian settlers had managed to significantly alter the landscape in order to create farmland and pastures.

1.3 MARSH ENVIRONMENTS

1.3.1 Salt Marsh

Salt marshes typically occur in regions were a distributary empties into an interdistributary bay, on a wide section of the river mouth or delta plains. They are also found in Arctic to the subtropics and can grow in a wide range of climatic conditions. Marshes play a critical role in sediment exchange with adjacent mudflats and open coastal water due to the transition between terrestrial and marine environments (Davidson-Arnott et al.2002). Also they act as sinks for sediment brought in both by runoff from nearby uplands and local tidal waters (Gordon et al., 1985a). Salt marshes are also generally areas of high productivity, a component of the food chain for the coastal waters and surrounding mudflats due the enrichment of organic material.

Morphologically, of salt marshes transform rapidly due to environmental influences such as, storms events, tidal amplification and sea level rise. Salt marshes do in fact have a consistent structure throughout the world. They consist of a gently sloping vegetated platform which is divided by a tidal creek system that increases in size and depth towards the coastline. They tend to be in areas of high net sediment accumulation which allows growth both vertically and horizontally (Davidson-Arnott et al.2002). Deposition and growth in salt marsh ranges from dominantly minerogenic, caused by accumulation of fine sediment deposited on the marsh surface, to dominantly organic, which consists of belowground organic accumulation producing substantial beds of peat (Allen, 2000). Under stable sea level the vertical growth a salt marsh is bounded by the tidal range of the area, hence growth of a salt marsh is greatest when engulfed with sea water under high tide conditions. Davidson-Arnott et, al. (2002) states that the rate of vertical growth of salt marshes, in particular mineralogic salt marshes, has shown rapid growth in the early phase and very low growth rates once a mature marsh surface is established near or above the mean high tide level (Cited from, Pethick, 1981; Allen, 1990; Jennings at al., 1993; French and Spencer, 1993;). During rising sea level conditions thick deposits can accumulate if vertical growth can keep pace with the rate of sea level (Allen,1990). Grand Pré core samples display a sequence of rapid sea level rise which overwhelms the rate of vertical growth.

The Grand Pré salt marsh is deposited by a part of the estuarine system due to the convergent of Gaspereau River and the Cornwallis River in to the Minas Basin. Mainly the growth of the marsh is due to the Macrotidal coastline which experiences repeated submergences every day for several hours.

This allowed the marsh to accumulate plant matter which often is dominated by species such as *Spartina alterniflora* and *Spartina paten*. With a foundation of plants on the marsh, deposition of fine grained sediments and organic matter creates vertical growth.

The arrival of the Acadian settlers transformed the marsh to what is seen today. The dykeing of Grand Pré to create farmland, caused the marsh never to experience tidal submergences again. This blocked deposition of fine grained sediment and organic matter and only allowed belowground organic accumulation for vertical growth. Therefore this eroded the coastline up to the dyked area and defined the present day coastline.

1.3.2 Sediment and Coastal Erosion

Marshes are typically cut by narrow channels of slow-moving water. Due to the sluggish movement of the water most of the suspended sediment is finely laminated silt and clay that settles out of suspension and deposits on the marsh. On macrotidal coastlines, such as the one at Grand Pré in the Minas Basin the channel system consists of generally straight, steep channels that are perpendicular to the shoreline(Davidson-Arnott et al., 2002). These channels operate as sediment conduits by transporting sediment between the marsh and the naubouring body of water. Also as the channels proceeds to the coastline it begins to widen at the mouth which is an area that mainly consists of mudflat (Davidson-Arnott et, al. 2002).

The sediment source and the volume of the sediment supply to a salt marsh relies the following key factors: marsh substrate, sedimentation patterns, rate of sedimentation and vegetation development on the salt marsh (Cahoon et al., 1996). In the Bay of Fundy the source of the large volumes of sediment are supplied through coastal erosion of glacial tills and cliff faces which create fine grained suspended sediment (Amos and Tee, 1989). This light fine grained sediment is therefore deposited on the marsh through tidal and wind energy.

In Grand Pré this process was accelerated at the time the dykes were being built by the Acadians. As the stages of dykeing occurred, water flow slowed drastically which caused even more sediment to settle out resulting in high sedimentation rates. When the dykeing of the marsh was completed the sedimentation rate stopped completely due to the fact that there was no tidal cycle. This process engulfed the marsh to the state which can be observed in the present day.

Sherman Bleakney in his book, Sods, Soil, and Spades, outlines evidence of shoreline evolution at Grand Pré. He's states that relic shorelines in the Grand Pré area fit into three categories. First is the western end of Long Island, which is exposed to prevailing westerly winds, the old shore deposit forms an exposed sea cliff about 3 metres thick, consisting of three different layers. One of the layers being salt marsh and ice rafted stones which is category one, storm-generated shore deposits. The second category is the tidal meadow (low marsh) fronted by sandy beach shoreline, these are located at the northeast corner of Grand Pré. The third category is the pure accumulation of marsh-grass turf (High Marsh) with entangled root systems which makes up most to the landscape in Grand Pré (Bleakney, 2004). This could only occur in protected backwaters such as the salt marsh behind the headland islands, Long Island, Boot Island and Little Island. These headlands play fundamental roles in the evolution of the coastline due to the fact that they act as breakwaters and act as a buffer zone in storm events and sea level rise.

1.3.4 Marsh Vegetation

There is abundant vegetation present on the salt marshes which is a source of organic matter that can eventually become peat. The marsh vegetation can also display root castes and burrows from various organisms. Salt marsh vegetation is divided into three stages; high, middle and low marsh communities which are dominated by *Spartina alterniflora* and *Spartina paten*. Plants in the low marsh experiences submergence twice a day of approximately six or more hours (D.B. Scott, 1977), whereas high marsh plants will only be submerged for brief periods once or twice a year during spring tides or during storm surges (Davidson-Arnott et al.2002).

1.4 MICROFOSSILS

In this study the microfossils which have be examined are benthic foraminifera which are in the Class Sarcodina. Foraminifera can be useful in marsh environments to determine paleo-elevations and marsh environmental types. The correlation of marsh foraminifera and marsh deposits can be useful in recreating an environment, particularly former sea levels. The relationship of marsh foraminiferal zonations to elevation above sea level and has been well established worldwide in several tidal regimes (Scott and Medioli, 1980, Smith et al., 1984). In Grand Pré the foraminiferal zonations will locate the former sea levels, marsh deposits and the main flooding surfaces.

1.5 HISTORY OF GRAND PRÉ DYKELANDS

The Acadians arrived in what is now Grand Pré, Nova Scotia in the early 1680s and immediately saw the potential of the marshlands along the coast of the Minas Basin. It was common practice to clear the forest in order to obtain land for agriculture, but the thin soils of mainland Nova Scotia were quickly depleted. The Grand Pré marsh offered inorganic, nutrient red mud with thicknesses of up to 12 m deep (Society Promotion of Grand Pré, 2002). The 1100 Ha (3000 acres) of land was also flat, rock-free, and stump-free (Bleakney, 2004).

To convert the Grand Pré marshland into productive agricultural land the Acadians had to overcome three problems: 1) they had to Prevent flooding of some by the world's highest tides; 2) the salt needed to be removed from the marsh sediments; and 3) in order to keep the sediment dry, the rainwater and surface runoff had to be able to drain away.

To overcome these issues the Acadians constructed a series of dykes made of earth and sods, which prevented the tidewaters from flooding the marshland. By placing a simple a device known as a sluice (or aboiteau), in appropriate locations along the dyke walls, the Acadians were able to drain the fresh water runoff off while stopping the influx of salt water from the Minas Basin. To leach the red mud of salt took only the rain and time. After two or three years the new soils were ready for cultivation.

The dykes had to be sufficiently high so that at high tide the salt water of the Minas Basin could not flow into the newly isolated marshlands. Fig. 1.4 outlines to varying dyke sizes for both man-made and machine-made dykes in the Grand Pré region.

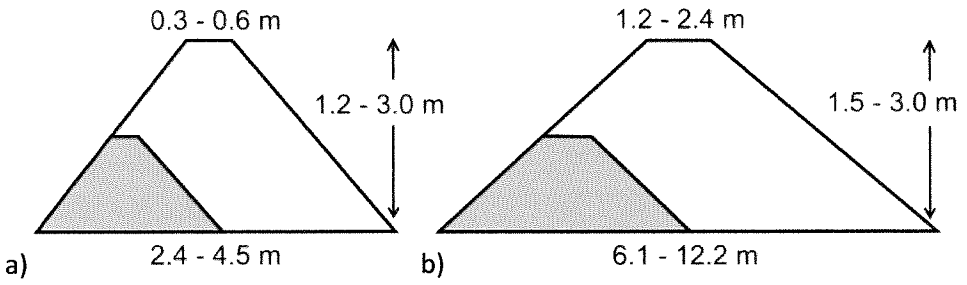


Figure 1.4: a) variations in size of hand-made dykes, b) variation in size of machine-made dykes (modified from Bleakney, 2004)

The dykes had to be carefully constructed to remain strong enough to hold back the ocean waters. Fig. 1.5 illustrates a cross section of a hand-built dyke wall. At the base of the dyke is the key trench with anchor posts. The inner fill is composed of packed sods and trimmings, and the exterior of the dyke is lined with precisely cut sods, typically made of salt-meadow grass. Sods used to construct the dykes came from sod pits, which were generally located on the marsh and were fairly close to the dyke construction site. The sods were placed grass side out and contained roots that ensured that the grass remained alive, which helped keep the walls solid. The sods had to be packed tightly to ensure there were no gaps and they were often stacked in a brick pattern for extra support.

A sluice is a hollow structure that passes through the base of a dyke and is placed at the mouth of a stream. It has a clapper valve that opens automatically to let water drain out from behind the dyke at low tide, and during high tide the rising water level closes the valve automatically.

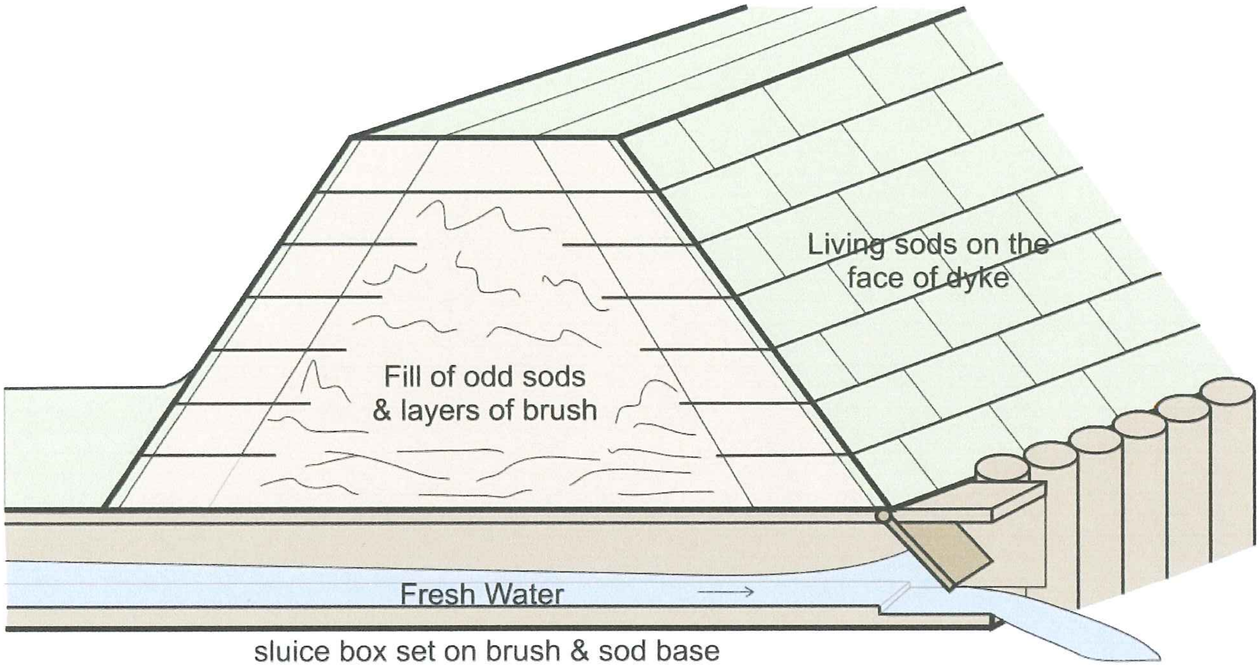


Figure 1.5: Diagram showing various features of dyke wall and sluice construction. Note the action of the clapper valve relative to direction of flow of water (modified from Bleakney, 2004).

The rise in sea level in the Bay of Fundy over the past 300 years has allowed preservation of the structures built on the Grand Pré marshland. Instead of being eroded away, they would have been buried by subsequent marsh deposits. The locations of old dykes have been determined by a combination of aerial photo analysis, ridge identification, and archaeological findings. The thick solid black lines in Fig.1.5 identify the dykes that still remain today.

Bleakney (2004) suggests that the dyke construction of the Grand Pré marshlands occurred in a minimum of 12 steps that would have been completed by the 1730s. The locations if these 12 enclosures are illustrated in Fig.1.6, with 1 being the first enclosure believed to have been built and 12 being the last. The shape of each enclosure would have been influenced by the original drainage configuration. Today only proximal dykes remain. Much of the land has been plowed and bulldozed, making it difficult to identify their exact locations.

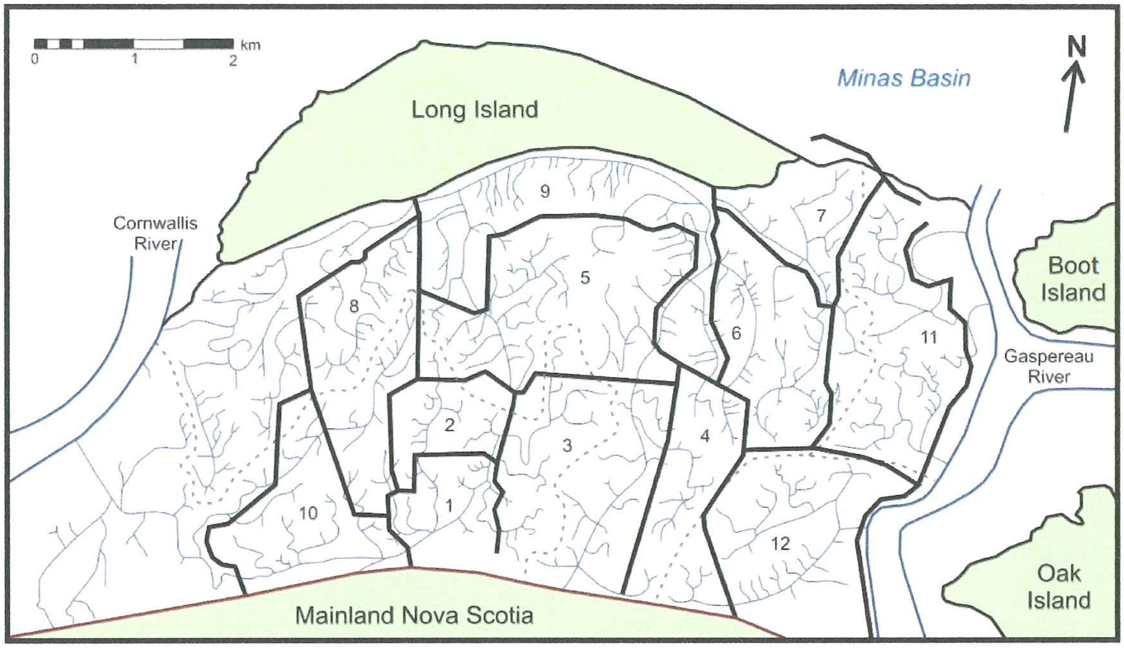


Figure 1.6: Map of the Grand Pré study area showing the locations of the dykes relative to the original drainage configuration. The order of enclosure is ranked numerically from 1-earliest to 12-latest (modified from Bleakney, 2004).

1.6 PREVIOUS WORK

The relationship of marsh foraminiferal zonations and tidal regimes has been well established in the Bay of Fundy and worldwide. A study conducted by Smith et al. (1984) in the Kingsport area, east of Grand Pré, focused on the marsh foraminifera zonations to determine higher high water markers in the Minas Basin. Grant (1970) suggested that higher-high water indicators (relative sea-level rise) is one half related to sea-level movement and one-half related to tidal amplification movement of the higher high water mark. Furthermore in Scott and Greenberg (1983) show that 4000 years before present (ybp) tidal amplification was over 80% complete in Minas Basin and that tidal amplification was a small component of sea-level rise after 4000 ybp. Other work has been completed by Smith et al. (1984) and Scott and Greenburg (1983) in Grandville Ferry, Fort Beausejour, Mary's Point and Chignecto Bay. Although none of these studies directly apply to the Grand Pré area they are locations that provide an analog model which can be applied to the Grand Pré marsh.

Recently John Shaw (NRCan-Bedford Institute) completed a study on the catastrophic tidal expansion in Bay of Fundy, using Grand Pré as one of the datasets. W. Harrison and C.J Lyon (1963) dated four in situ stumps of white pine at Grand Pré at elevations down to 1.6 m below mean tide level and the dates range from 3100-4450 years before present. This gives evidence that submergence rates indicated were greater than the average rate of postglacial rise of sea level, and the high water level increased at a rate of 46.2 cm/1000 years (Shaw, 2009). A suite of 9 dates from Grand Pré was published by Bleakney and Davis (1983) from four trees which range from 3675-4455 yr BP and three from a flat bed of American oysters that range 3615-3750 yr BP. Also two dates are from ribbed mussels shells which range from 3310 and 3800 yr BP. These samples are critical because they strongly constrain tidal ranges due to the environments of each sample. The trees are supra-tidal, the ribbed mussels are intertidal and the oysters are subtidal.

Sherman Bleakney has conducted numerous studies which he outlines in his book Sods, Soils and Spades. He has summarized the history of the Grand Pré Marsh evolution since the arrival of the Acadians in the 1680s. Further insight into the development of Grand Pré has lead to the launch of the study.

1.7 ORGANIZATION OF THESIS

Chapter 2 will outline the methods used in collecting and analyzing the data acquired as a part of this thesis. Chapter 3 provides a detailed account of all of the results from this study of the Grand Pré core analysis including lithological descriptions and microfossil examination. Chapters 4 and 5 discuss the relevance of the results and recommendations for future work.

2.0 Methods

In the Grand Pré project there is a series of scientific methods used to describe the past geologic environments. Some of these methods include, vibracoring, logging of the vibracore and core correlation, sampling the cores, and examination of the samples for microfossils. The methods used are not new techniques and are published in Scott et al. (2001).

2.1 VIBRACORING

A vibracore is a device that uses vibration to drive the core barrel into the ground. This process is often used in soft sediment areas similar to the Grand Pré marsh. A gas powered generator provides the power to the vibration device which is connected to an aluminum pipe. The vibrations cause a disturbance in the sediment which allows the core to penetrate into the ground. The disturbance within the core is minimal and all sedimentary structures are preserved. Following the collection, the core was split with a circular saw into two halves; one half is the working sample and the other is the archive sample.

For this study 7 cores were collected from 3 different locations (Fig. 1.3). The cores were collected by Dr. D.B. Scott and Pete Van Hengstum from Dalhousie University and Rob Ferguson and Katie Cottreau-Robins from Parks Canada. The cores were collected on October 14, 2008 and split on October 16, 2009. Cores 1 and 2 were taken from the Grand Pré archaeological dig, cores 3 and 4 from 50 metres north of the dig site and cores 5, 6, and 7 from the dyke near the eastern shoreline of Grand Pré. These core were originally taken in an attempt to locate archeological features in the subsurface, therefore their locations were chosen based on historical information to help to find sluice gates and dykes. The only core which penetrated a dyke was core 6; this core displayed a majority of anthropogenic sediments and had minimal marsh present.

2.2 CORE LOGGING

All seven of the cores collected were examined for grain size, colour, presence of fossils, organics, and sedimentary structures. The colour is determined using the Munsell soil colour chart and grain size was determined using the Corelab Grain Size Chart. These characteristics were used to determine facies changes within the core. The table below outlines the criteria used to classify the different depositional environments. In addition to lithological descriptions microfossil analysis of the cores to verify the facies changes.

Table 2.1: Description of marsh facies

Facies	**Facies Description**
High Marsh	Reddish-Brown due to Oxygenation, medium – fine grained mud, chunky mud
Middle Marsh	Brownish-Yellow, high in organics, modeling of clays, fine mud, clay, micas (differences in middle marsh and low marsh determine by microfossils)
Low Marsh	Brownish-Yellow, high in organics, some lenses form tidal activity.
Intertidal Mudflat	Red – Dark Brown, very fine sediment, lenses of coarser material suggesting tidal activity, Macrofossils
Mudflat	Red- Dark Brown, very fine sediments, no organic, high sedimentations rate, silts, clays, macrofossils

2.3 SAMPLING AND PROCESSING

Once the core descriptions were compete, a series of 10 cc samples were taken from each core. A sample was taken from every facies interval found in each core. If the interval was large greater than 50 cm then 2 samples were collected. Sample locations are identified in Appendix A. The sample material was washed and passed through a 500 µm sieve to remove any large grains or organics and was then passed through a 63 µm sieve to remove the silt and clay. The microfossils of interest range from 500 - 63 µm in size and any present in the sample would be isolated by this washing process.

The washed sample was then placed in a solution of water, 98% alcohol plus borax to help preserve the sample for short term storage. For long term storage the samples were placed in a formaldehyde solution and are placed in cold storage at 2°C. When the samples were ready for examination samples were washed again to remove the formaldehyde and placed back in the water, alcohol, borax solution.

2.4 MICROFOSSIL IDENTIFICATION

A Leica Microscope with up to 4x magnification was used in the microfossil identification. These microscopes have a detached light source which illuminates the sample for viewing.

Each sample was placed in a plastic Petri dish which is sub-divided into square segments for examination. These segments are used for counting fossil abundance. The fossils are counted in each square and then tallied for a total count. If a sample contained a high quantity of fossils so that counting became difficult in this manner, the sample would then be divided using a wet-splitter (Scott and Hermelin, 1991). The splitter divides the sample into 8 individual sub-samples which can then be looked at individually. If the fossil count remains consistent throughout the first 4 sub-samples the average of those counted can be multiplied by eight to give the total count for the sample. Relative abundances were then calculated in order to display the information graphically.

Identification of microfossils are very important to verify the facies changes within the cores, since facies changes may not always be visible based on the characteristics described in the core logs. Each microfossil species represents a different marsh environment; for instance *Elphidium williamsoni* is associated with intertidal mudflat deposits. The samples which are collected are glued on a display plate and photos are taken using a Scanning Electron Microscope.

2.5 CORE X-RAY:

The core x-ray images were completed at the Bedford Instuted of Ocean Tecnogholoy by their lab technician Kate Jarrett. The purpose for this technique is to examine the calcareous materials throughout the cores. In this case the calcareous layers which are of interest are the gastropod layers.

Therefore this will highlight these areas and prove useful in correlation and interpretation of the core samples.

2.6 DATING

A sample from Core 2 was sent to Beta Analytic Inc in Miami, Florida to be dated using standard radiometric. First a 40 gram sample was collected from core 2 at 373-376 cm which was packaged and sent to Beta Analytic Inc. When the sample arrived at Beta Analytic the sample was then washed in acid, in preparation for dating. The dating is a carbon 13/carbon 12 dating ratio which was preformed over a course of approximately three weeks. Once complete the result is a Radiocarbon age is then calibrated by 2 sigma calibration with a 95% probability factor. Appendix B outlines the calibration of radiocarbon age to calendar years. The dating would have not taken place if not for the funding supplied by Parks Canada.

3.0 Results

3.1 CORE SEDIMENTOLOGY

The seven cores collected at the Grand Pré site were logged and examined in detail. Found at the top of each cores were anthropogenic sediments of varying thicknesses. This sediment was deposited by tidal and flooding sequences which occurred after the Acadians built the dykes to create farmland. This sediment is a reddish colour due to oxidation, and there are organics present but these intervals displayed no sedimentary structures and contained no microfossils in the post- Acadian era. This anthropogenic sediment is different in each core due to the location on the farmland where the sample was collected. Cores 1 and 2 have red anthropogenic sediment in the upper section of the core (~40-45 cm) whereas cores 3 and 4 display red anthropogenic sediment at 145-155 cm. This is a result of much more intense farming or the operation of heavy equipment for farming purposes and also road building. Furthermore the sediment was disturbed because of the farming method called crowning where the farmland was plowed annually keeping the farm land level. This would only affect the upper part of the marsh and is well displayed in the cores. The following sections compare and contrast all 7 cores. Each core is grouped with others taken in the same location. Appendix A shows images of the core along with the core descriptions, foraminifera analysis results and facies interpretations.

3.1.1 Cores 1 &2

The first 45 cm of core 1 is made of red oxygenated mud followed by dark brown soil with black and yellow modelling. The sediment from 68 to 115 cm presented black modelling and organic matter abundant in areas. In the 115 to 150 cm the soil changed to gray in colour and black modelling with no structure. This continued until 216 cm mark where it changed to yellowish grey colour with large black modelling and gastropods fossils. These gastropod fossils were observed in 1 cm thick layers which only consisted of gastropod fossils. This gastropod rich interval continues until the 342 cm mark then changed to black soil down to 361 cm. At 361 to 385 cm the soil changed from black to light grey colour with dark modelling throughout. The base of the core contains very dark mud with no structure or modelling.

The first 41 cm of core 2 indicates red oxidation to orange coloured mud which continues into a light grey colour with yellowish brown modelling. Also there is calcareous material within the mud and no structures are present. At 85 cm the sediment changed to the light grey and to dark grey, continuing to the 150 cm mark. This section displays dark grey bands, organic rich mud and gastropods fossils. From the 150 to 250 cm the colour changed to medium grey colour and has yellowish lenses, grey modelling and gastropod fossils, which may represent storm deposits. In the 250 to 285 cm section the colour changed to yellowish grey and displays black modelling and from 278 to 380 cm the colour changed to light grey with thick black lenses which could represent storm deposits.

Cores 1 and 2 were collected metres apart from each other and show close similarities at approximately the same levels. The gastropods occurred at a higher level in core 2 but the difference was marginal.

3.1.2 Cores 3 & 4

The first 57 cm of Core 3 displays reddish brown oxygenated mud with no structure, modeling or fossils. From 57 to 150 cm displayed undisturbed reddish brown marsh mud with black modelling throughout. This could be anthropogenic or oxidized marsh sediments. In the 150 to 342 cm interval there was a major change in colour from reddish brown to grey with heavy black modeling throughout along with the presence of gastropod fossils.

Core 4 shows the top 180 cm to be anthropogenic sediments which is a result of the sampling location being near a road. The first 180 cm was reddish brown mud and displays heavy organics throughout the core. From 180 cm to the bottom fine grained gray mud which black peat modeling, also there are fine layers of gastropods.

3.1.3 Cores 5, 6 & 7

Core 5 is the core which was collected on top of an Acadian dyke. The core indicates anthropogenic sediments with red oxidized mud to approximately 125 cm. This top portion is believed to be the relict Acadian dyke. There is only one facies throughout 125 -300 cm which is gray fine grained mud rich with black organic modelling. The modelling is very heavy towards the bottom of the core.

The first 98 cm of Core 6 displayed as a brown mud with black to yellowish modeling which occurred approximately every 10-20 cm. From 98-140 cm the core is brown in colour and displayed orange modelling. This core potentially was all anthropogenic due to the short length and a sampling problem with the core pipe.

The first 78 cm of Core 7 showed anthropogenic sediments. From 78 to 259 cm the core had a grey to brown colour throughout the facies and changed in colour represents a change in interval. The section consisted of black modelling, black laminations, root material, large chunks of black organics and some defined bedding. From 259-288 cm there was a greenish grey colour which includes intervals of brownish green sediments with increase in depth. From 288 to 452 cm the core had a brown colour with an abundance of organic material along with black laminations and black modelling. This was the longest core of the group of cores and should provide the best record for the Grand Pré area.

3.2 CORRELATION OF THE CORE

The cores collected from Grand Pré demonstrate a complete correlation of the anthropogenic sediments and an almost complete section of the marsh sediments. The anthropogenic sediments are well defined throughout each core, displaying red oxides sediments in the upper most part of each individual core. The marsh sediments provide a well defined correlation among cores 1,2,3 and 4 which is shown in Fig. 3.1 There is sharp contact between the high-middle marsh and the mud flat environment which can be seen in the facies change in the core and with the change in marsh foraminifera. Core 5, 6 and 7 only displays high-middle marsh sediments with considerable variation throughout each. A representative cross-section illustrating the core correlation can be seen in Fig. 3.1.

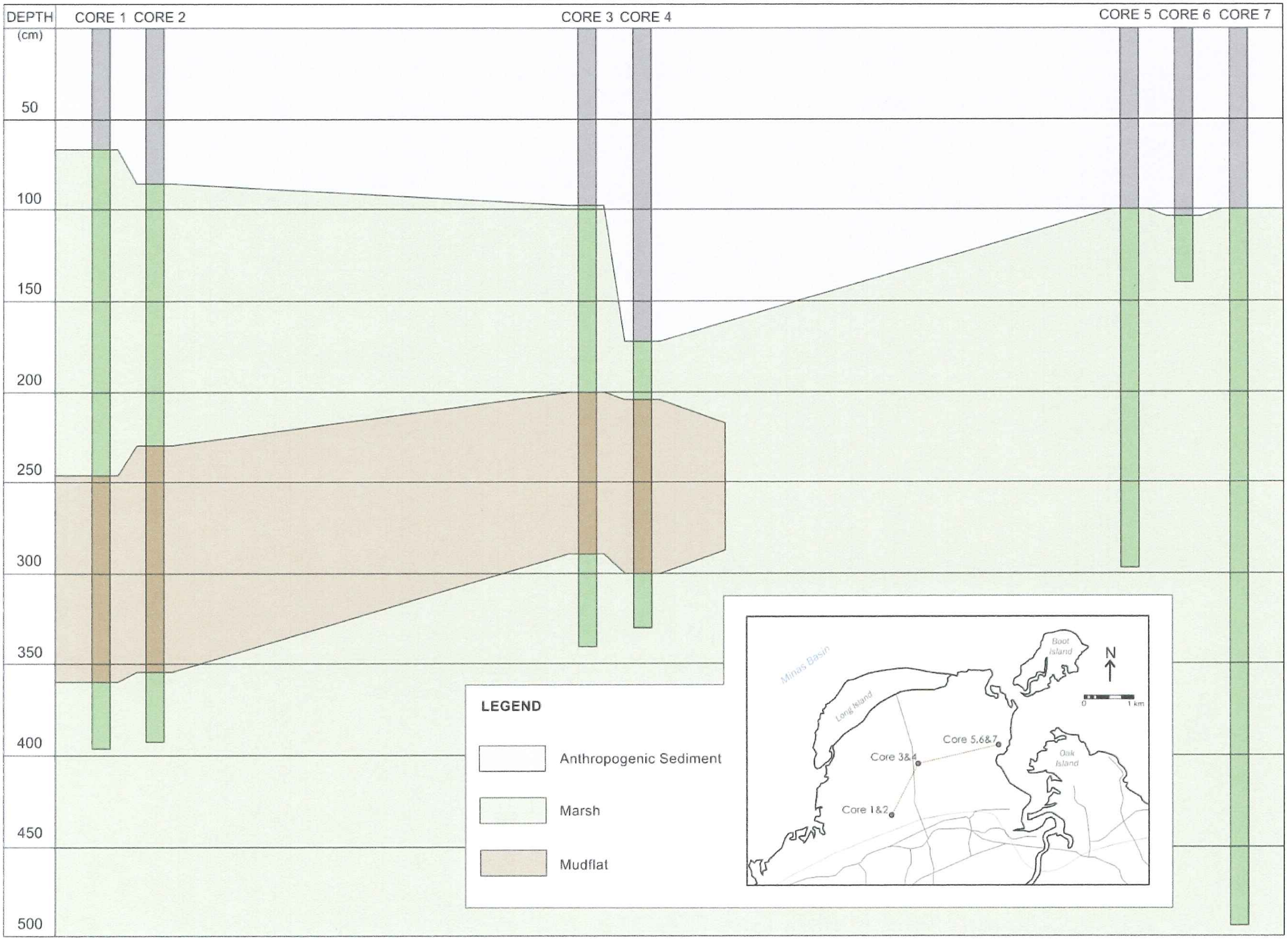


Figure 3.1: Illustration showing the correlation of the different facies established between the cores.

3.3 MICROFOSSIL ANALYSIS

3.3.1Foraminifera

The distribution of the marsh foraminifera throughout the Grand Pré provides detailed data on the environmental history of the marsh. The data which is provided in Appendix C illustrates the abundances of foraminifera verse the depth of the core. The data collected supplies environmental information needed to recreate the environmental history of Grand Pré prior to the arrival of the Acadian settlers. Fig. 3.2 displays correlation of each foraminifera species from Core 1 and demonstrates the environmental zonation. Note that species are labeled from (Sp) 1 through 9 and are outlined in Tables 3.1 and 3.2. Each data set represented in Fig. 3.2 shows relative abundances of marsh foraminifera in relative percent.

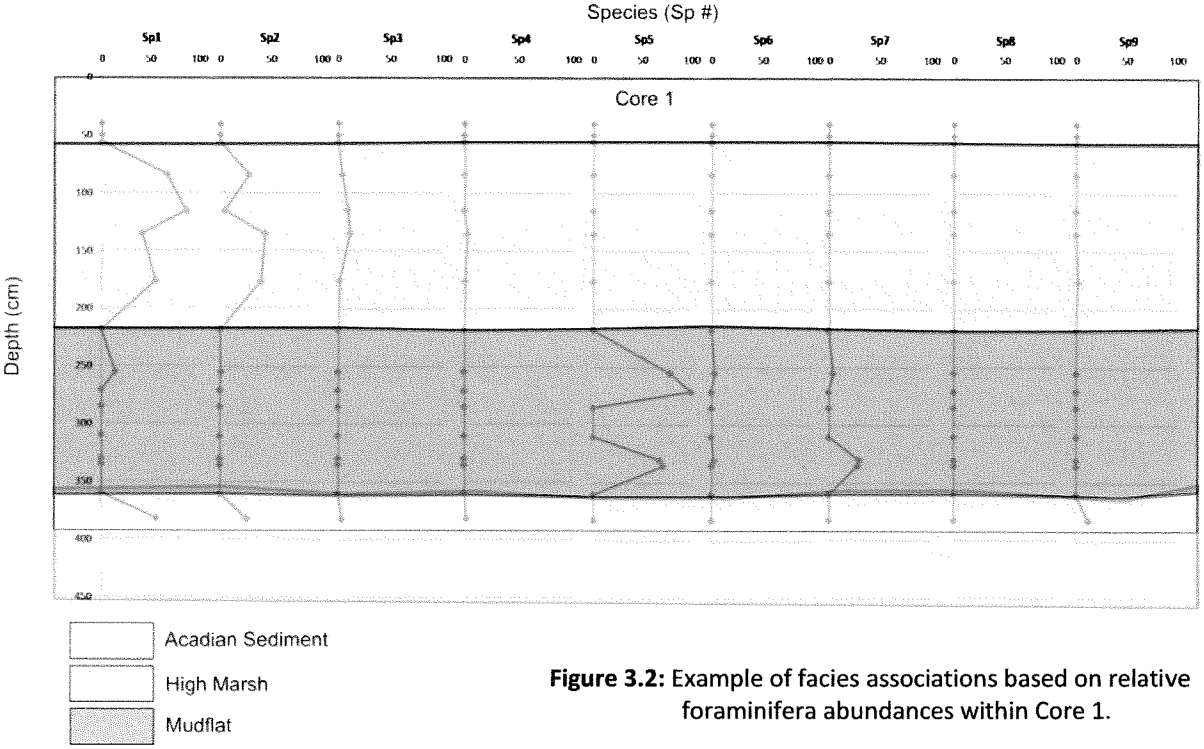
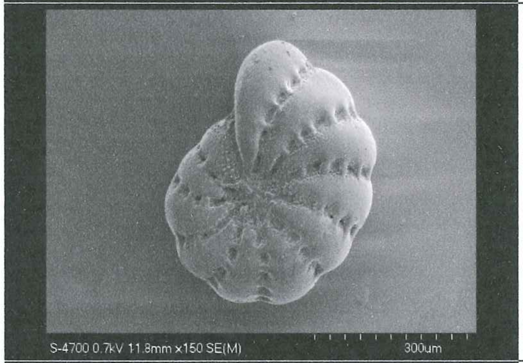


Figure 3.2: Example of facies associations based on relative foraminifera abundances within Core 1.

Table 3.1: Marsh Foraminifera of Grand Pré (from Javaux and Scott, 2003).

Abundant Marsh Foraminifera of Grand Pré		
Photos	**Species**	**Descriptions**
	*Trochammina inflata,* **(Sp 1)**	High marsh, very high abundant, the most populated species of Grand Pré
	*Tiphotrocha comprimata* **(Sp 2)**	High marsh, very abundant aggulated
	*Trochammina macrescens f. macrescens* **(Sp 3)**	Highest marsh, not very abundant, agulated
No Image Available	*Arenoparella mexicana* **(Sp 9)**	Middle to low Marsh, abundant, aggulated
	*Pseudothurammina limnetis* **(Sp 5)**	Marsh, only found in one sample.
	*Trochammina macrescens f. polystoma* **(Sp 4)**	High to middle marsh, abundant in some samples, aggulated

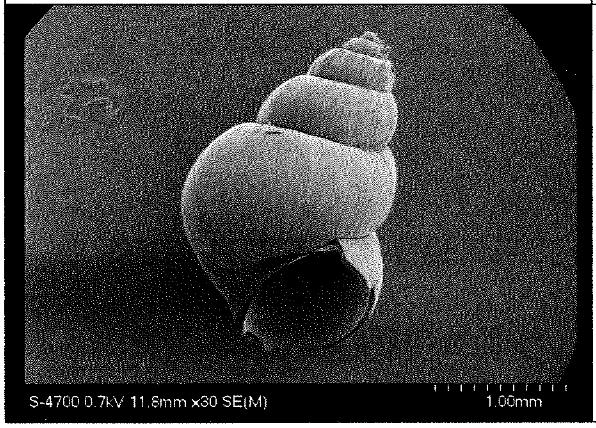
Table 3.2: Mudflat Foraminifera of Grand Pré (from Javaux and Scott, 2003).

Abundant Mudflat Foraminifera of Grand Pré		
Photos	**Species**	**Descriptions**
	*Elphidium williansoni* **(Sp 6)**	Mud flat, very abundant, calcareous
	*Elphidium advenum* **(Sp 7)**	Mud flat not abundant, calcareous
	*Haynesina orbiculare* **(Sp 8)**	Mudflat , not abundant, calcareous

3.3.2 Gastropods

The distribution *H.totteni* in intertidal areas is distributed across three general habitats, high to middle marsh (upper intertidal), low marsh (lower intertidal) and mudflat (intertidal). *H.totteni* is rare in the upper intertidal zone averaging 9800+/-400 m^2 , in the lower intertidal and mudflat zones densities are much higher, averaging 19,000+/-2200 m^2 (Wells, 1979).

Table 3.3: Gastropods of Grand Pré.

Gastropod Identification		
Picture	**Name**	**Habitat**
	*Hydrobia totteni*	Intertidal mudflat areas, salinity ranges 27.6-29.2 mg/L .

3.4 DATING RESULTS

The dated organic material was collected from core two at a depth of 373-376 cm and gave an age of 2700+/-50 YBP. This date is very valuable, and provides the age of the higher high water marker and the contact between the higher high water and lower low water marker. From this, sea level is suggest to be at approximately 3.8 metres. This can be used against other sea level curves complete in the Minas Basin, particularly the Kingsport and the curves. Table 3.4 describes the results from Beta Analytic, Inc dating of core 2 sample 373-376 cm.

Table 3. 4: Carbon-14 age dating results from Bata Analytics Inc.

Item	**Description**
Beta ID	27423
Received	Thursday
Submitter No.	2009-Grand
Service	Radiometric-
Material Pretreatment	(marine sediment):
Measured Age	2700 +/- 50
13C/12C	-21.6 o/oo
Conventional Age	2750 +/- 50 BP
2 Sigma Calibration	Cal BC 1010 to
Report Completed	Wednesday

3.5 SUMMARY OF RESULTS

The information acquired from the data collected at Grand Pré suggested it has a unique story. Anthropogenic contamination of the cores was initially believed to be issue in identifying different facies within the core samples, but this did not end up being a problem. The anthropogenic sediments could be easily recognized by red oxidized mud at the top of each core. Below the anthropogenic horizon the majority of each core displayed dark fine grained mud's throughout. The facies changes were noted by the presence of gastropod layers which represented mudflat environments the presence of peat and organic materials represented marsh environments. Moreover this could be directly related to the samples collected for foraminifera analyses. The marsh sections of the cores displayed foraminifera which are well known around the world as marsh species (*Trochammina inflata, Tiphotrocha comprimata, Trochammina macrescens f. macrescens, Arenoparella Mexicana, Pseudothurammina limnetis, and Trochammina macrescens f. polystoma*). Therefore the mudflat sections of the cores also displayed foraminifera which are well known mudflat living species (*Elphidium williansoni, Elphidium advenum, and Haynesina orbiculare*). The correlation of the core descriptions and the sample descriptions was a direct match which can confirm the type of environment in each facies of the cores. From this it can be determined that the marsh environments observed in the cores was high to middle-high marsh due to the overwhelming presents of *Trochammina inflata* and *Tiphotrocha comprimata*. It can also be determined that the mudflat environment is an inter-tidal mudflat zone due to the high abundance of *Elphidium williansoni* and presence of gastropods. The presence of gastropods are very important due to the fact that they live in an inter-tidal region. This secures the fact that the facies was an inter-tidal mudflat. Determining the facies was very important factor in determining the higher-high water [HHW] marker and the lower-low water indicator [LLW] which can provide details about the evolution of the Grand Pré coastline and marsh environment. In this case the HHW is the marsh facies in core 1, 2, 3, and 4 which ranges from 0-2.1 metres and 3.8 metres continuing down and in core 5, 6, and 7 marsh facies is completely throughout the core. The mudflat is the LLW indicator and approximately 1 metre in each core spanning 2.1-3.8 metres illustrated in Fig. 3.1 and is not present in core 5, 6, and 7. Furthermore each depth of facies change can be compared to other studies completed on marsh environment in the Bay of Fundy. Also the data collected from core two between 3.73-3.76 metres is a marsh facies interval and was used to determine the age of the HHW mark at that depth. This is essential for correlation with other studies and can also determine if tidal amplification played a role in the facies change.

4.0 Discussion

At present the extreme amplitudes of the Bay of Fundy tides shapes the coastline of the Minas Basin on a daily basis. In Grand Pré the marsh demonstrates zones of a high tidal marsh (HHW) and a low water inter-tidal estuary (LLW) which is determined by the foraminiferal zoneations. The HHW mark is displayed at approximately the 3.0-3.8 metre. At this depth the contact between the HHW and LLW presents a tremendous change in facies over a few centimeters. The contact is dated in core 2 to be 2700 +\- 50 YBP. At 2.5-2.1 metres the next facies change occurs from LLW to HHW; again this is a tremendous change in facies. This environmental change seems like a classic transgression and regression sequences of a tidal zone, but numerous studies conducted in the Minas Basin suggest with certainty that this was not the case at Grand Pré. Other explanations for this environmental change could be either the result of rapid changes caused by extreme tidal amplitudes of the Bay of Fundy, local sea-level rise, or a storm event.

A study using foraminifera zonations to recreate the environment has never been conducted at Grand Pré; therefore, other studies completed in the Minas Basin play a considerable role in understanding the data collected. The study conducted by Smith et al. (1979) and Scott and Greenburg (1983) is the most closely related to this type of study. The Smith et al. studies the lithologies and foraminiferal occurrences through core samples of Kingsport marsh, Granville Ferry marsh (Annapolis Royal), Mary's Point marsh, and Fort Beausejour marsh. Moreover Scott and Greenburg study using the Smith et al. data to create relative sea-level rise and tidal model for the Bay of Fundy. These studies display similarities in each area, but also display major geological differences which suggest that each area is locally different. This is also the case for Grand Pre, displaying a unique coastal evolution in the Minas Basin but displaying similar foraminiferal results. Another key factor of the coastal evolution is tidal modeling which demonstrates that the tidal range greatly expanded during the Holocene in the Bay of Fundy. The study completed by Scott and Greenburg (1983) suggest that the tidal range increased much more rapidly from 7000-4000 YBP then 4000 YBP to the present. Also it was suggested that the tidal amplitude 5000 YBP was almost 80% of its present range and is directly related to changes in water depth on Georges Bank (Shaw et al. 2009). A similar study was conducted by Gehrels et al. (1995) concluded that tidal range in the Bay of Fundy was: 54-59% at 7000 YBP, 73 % at 5000 YBP, 78% at 4000 YBP, 85 % at 3000 YBP, 94% at 2000 YBP, and 98% at 1000 YBP. The dates which apply to this study are 3000-2000 YBP because the contact between the HHW (High Marsh) and LLW (Mud Flat) is represented at 2700+/-50 YBP. Therefore Grand Pré experienced 15% tidal change over the past 3000 years. This change may have played a role in the coastal evolution in Grand Pré during the last 3000 years.

Furthermore the Windsor mudflats generated marsh within 60 years of the building of the Windsor causeway thus comparison can be made explaining the events at Grand Pré. The pattern of sediment concentration during flooding of the mudflat displays a mean concentration ranging between 26.3 and 93.5 mg/L (Amos and Mosher, 1985). This large fluctuation of 37% is a resultant of the local weather conditions and varies spatially by 20% due to the relative inputs of fresh water through sluices of the causeway (Amos and Mosher, 1985). It was concluded by Amos and Mosher (1985) that newly deposited intertidal sediment of the Bay of Fundy was 80 times more resistant to erosion than other marine sediments from different areas. Reported by Dunn (1959) intertidal sediment was erosion resistant with properties similar to ephemeral, fresh-water cohesive channels. Presumably the sediment was compacted due to drying and solar heating during tidal cycle exposure which consolidates and hardens the sediments causing the mudflats to have a higher resistances to erosion (Amos and Mosher, 1985). Kamphuis and Hall (1983) established a relationship between consolidation and erosion resistance that can be linked to resistance to erosion of intertidal sediments that decreases seaward due to a reduced time of exposure (Amos and Mosher, 1985).

The observations made by Amos and Mosher can be used to compare newly deposited sediments at Grand Pré. At Grand Pré the Cores 1 and 2 which are closest to the mainland developing marsh organics earlier than Cores 3 and 4. Using Windsor mudflat data to compare suggests that Core 1 and 2 where at a higher part of the tidal range which created a elevated resistances to erosion. This allowed marsh organics to accumulate and grow marsh whereas Core 3 and 4 must have been at a lower part of the tidal range creating a lower resistance to erosion not allowing marsh to accumulate.

The aforementioned evidence can help to facilitate the story of the evolving coastline at Grand Pré. The data collected suggests before 2700 ybp Grand Pré was entirely high marsh approximately 1 -2 kilometers in the northwards direction into the Minas Basin and almost connecting Starrs Point and Kingsport separated slightly by Cornwallis River (Fig. 4.1).

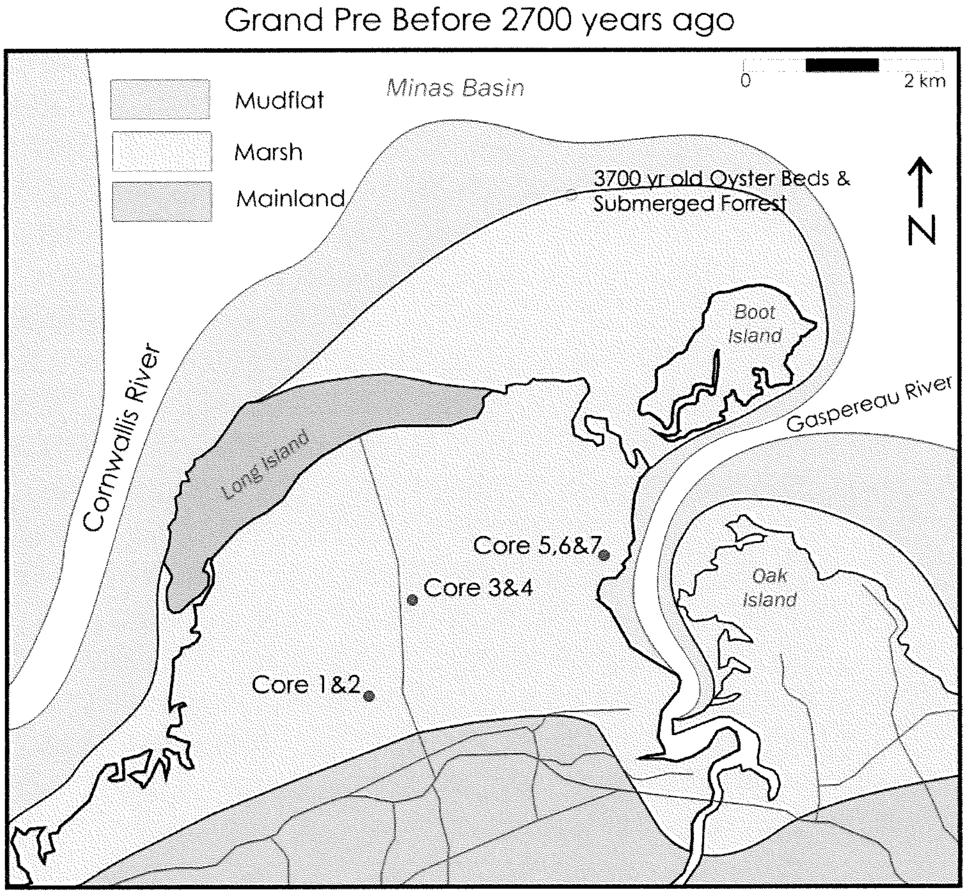


Figure 4.1: Illustration of Grand Pré before 2700 years ago based on interpretation of facies within the core collected in this study and by dates by Sherman Bleakney of oyster beds and submerged forests.

This high marsh would have experienced similar conditions of a salt marsh which can be observed today. Excellent examples of these are the Chezzetcook Inlet salt marsh and Chebogue Harbour which experience 2 tidal cycles a day (D.B Scott, 1977). Furthermore Bleakney and Davis 1983 discovered 3700 year old American Oysters along with tree stumps located 2 kilometres north of Boot Island.

The relative sea level curve illustrated in Fig. 4.2 uses data from Kingsport and from Grand Pré which is plotted on a sea level that Scott and Greenberg (1983) constructed. This can be accepted due to the fact that Kingsport and Grand Pré locations are only kilometres apart from one another.

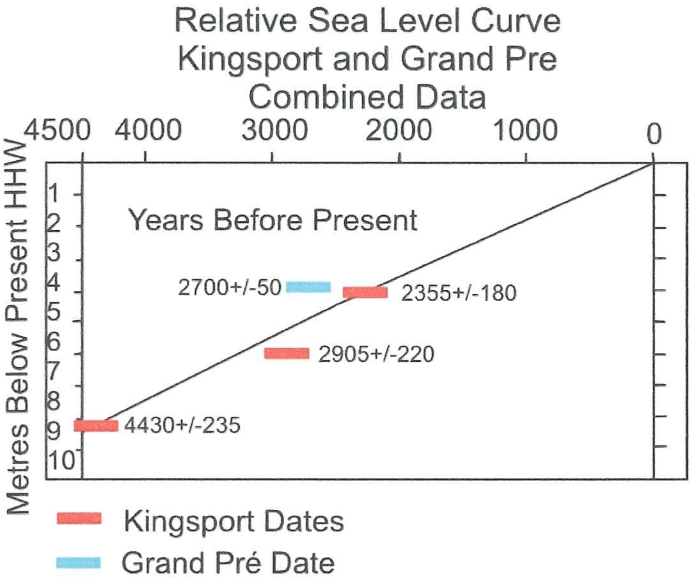


Figure 4.2: Combined relative sea level curve for Kingsport and Grand Pré (modified from Scott and Greenburg, 1983).

Sea level curves created by Scott and Greenberg (1983) at Mary's Point and Granville Ferry can also be compared with the date collected at Grand Pré (Fig. 4.3). Although these locations are not as close to Grand Pré as Kingsport, they are still located in the Bay of Fundy and can provide a solid foundation for sea level rise in the Minas Basin. First the Granville Ferry data displays dates at 2725+/-130 YBP at a depth of 3.5 metres and 3050+/-140 YBP at 6 metres. This correlates very well with the Grand Pré date of 2700+/-50 YBP with the depth of 3.8 metres. The other sea level curve from Mary's

Point also demonstrates excellent correlates displays dates 2225+/-160, 3130+/-180 , 3240+/-160 and 3640+/-180 YBP and at depths of 3.5, 5.1, 6.1, and 9.8 metres respectively. The Grand Pré data is plotted on Granville Ferry and Mary's Point sea level curves to illustrate the correlation between dates (Fig. 4.3).

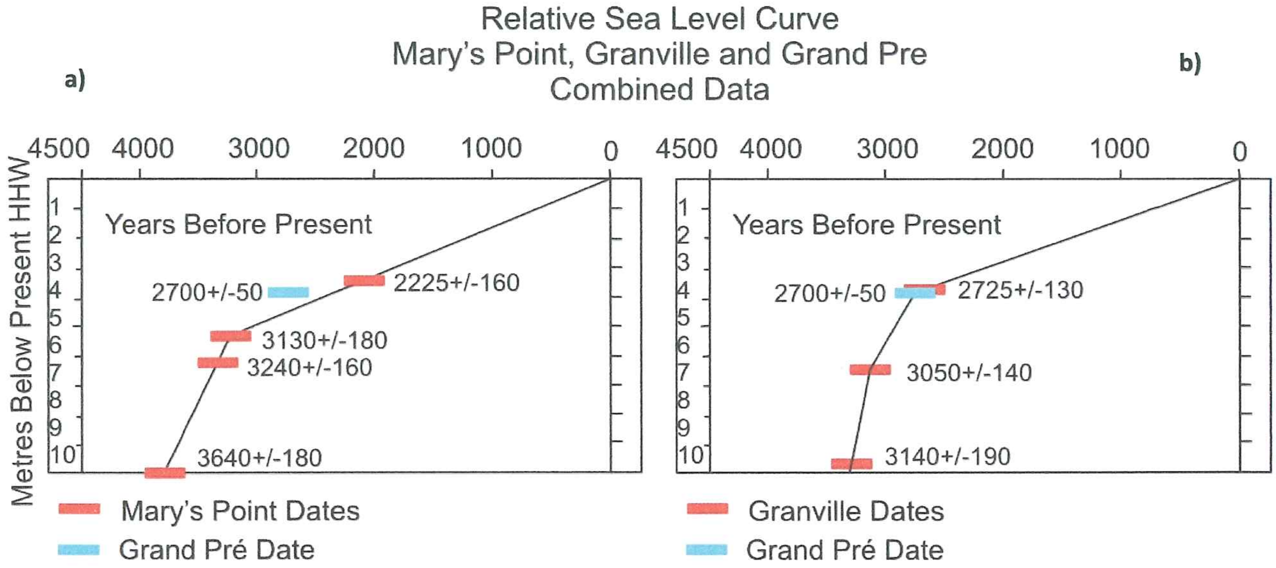


Figure 4.3: Combined relative sea level curve for a) Mary's Point and Grand Pré, and b) Granville and Grand Pré (modified from Scott and Greenburg, 1983).

Therefore this proposes that prior 2700 years ago the coastline was regressing while sea level and tidal change was at a standstill or rising. The Kingsport data supports this theory, displaying the HHW marked a 2905 +/- 220 YBP and 2355+/-180 YBP (Scott and Greenberg, 1983) which suggests at that time sea level was rising linearly at a slow rate of 3 metres every thousand years. The sea level curves (Fig. 4.2 and 4.3) have been modified from Scott and Greenburg's models to incorporate the Grand Pré date into a line of best fit. Due to the curves created incorporating Grand Pré data no major changes are represented in sea level rise which suggests that the incursion of mud was contributed by a local sea-level rise event.

This local sea level rise caused an extreme change to the Grand Pré that occurred at 2700 YPB on the eastern coastline and infiltrated the mainland. A large influx of sediment caused the eastern coastline to fill with mud creating an intertidal mudflat (Fig. 4.4).

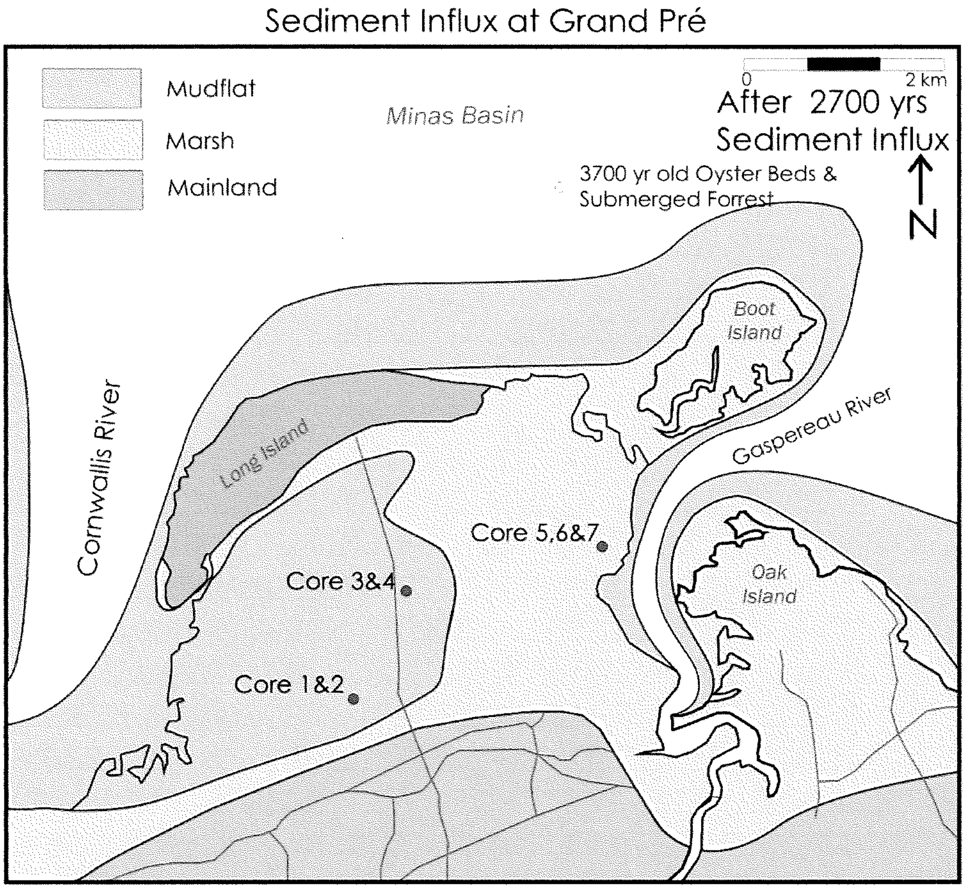


Figure 4.4: Illustration of Grand Pré after 2700 years ago based on interpretation of facies within the core collected in this study.

This mudflat penetrated inland approximately to the middle of Grand Pré and south of Long Island. The western side of Grand Pré was not affected supported by the data collected in cores 5, 6, and 7 which show only high marsh. Also this area is slightly higher in elevation by approximately 2 metres and is protected by Long Island and Boot Island that displays the farthest extending coastline illustrated in Fig. 4.1 and submergence due to sea level rise is illustrated in Fig. 4.3. It can be suggested that the influx of sediment creating the mudflat was caused by local sea-level rise or a major storm event that completely reworked the coastline; however, the data collect at Grand Pré supports no evidence of a major storm event. The core samples display very little change from one facies to another and do not show any coarse grained sediment which coarsen upwards.

The sediment influx generated an east to west transgression of the coastline which is represented in 1 meter of the cores 1, 2, 3, and 4. It can be deduced that a local sea-level rise of approximately 1-2 metres occurred due to the fact that high marsh is 1-2 metres above sea-level. The nature of sediments dynamics plays an important role in the transition from a high marsh to a mudflat. The suspended sediment which was carried over the high marsh, quickly slowed down and settled to the marsh surface, indicated by the presents of tall *Spartina paten* in these horizons.

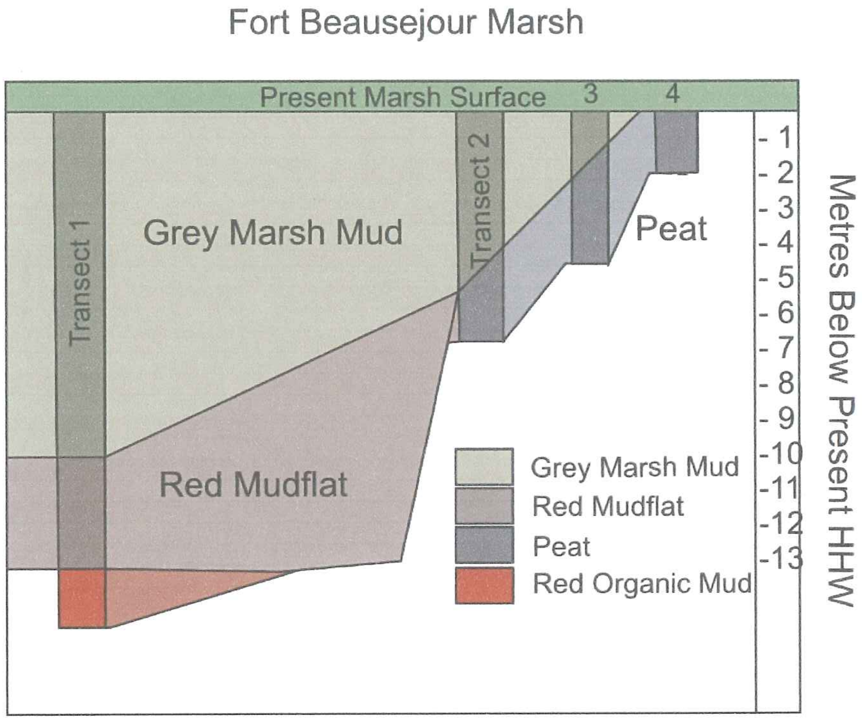


Figure 4.5: Illustration showing the influx of red mudflat at Fort Beausejour (modified from Smith et al., 1984).

A similar event of an incursion of red mudflat mud is displayed in Fort Beausejour at 11.5-6 metres (Smith et al., 1984)(Fig.4.5). Fort Beausejour is located in Chignecto Bay, a comparable geological setting to Grand Pré and the Minas Basin. Also Fort Beausejour and Grand Pré show no evidence of *Milliammina fusca* which is very common foraminifera in low marsh and mud flat settings (Smith et, al., 1984). Furthermore according to Scott and Greenberg, (1983), Chignecto Bay and the

Minas Basin experienced similar relative tidal regimes and sea-level rise. Therefore Fort Beausejour can be used as a geological model which represents a foundation for the evolution of the Grand Pré coastline proposal. Though direct correlation cannot be observed, similarities are evident which aids in the theory that comparable episodes can occur.

After the incursion of sediment the high marsh began to rebuild slowly from the outer edges of the coastline to the center of Grand Pré (Fig. 4.6). This developed a tidal creek system which covered the area over Cores 3 and 4 and developed seaward. This is a similar developed to the Windsor mudflats and Allen creek marsh, (Cumberland Basin) (Davidson-Arnott et al. 2002). As stated previously Cores 1 and 2 and not a part of the creek bed due to the fact of the high resistance of erosion and marsh coverage.

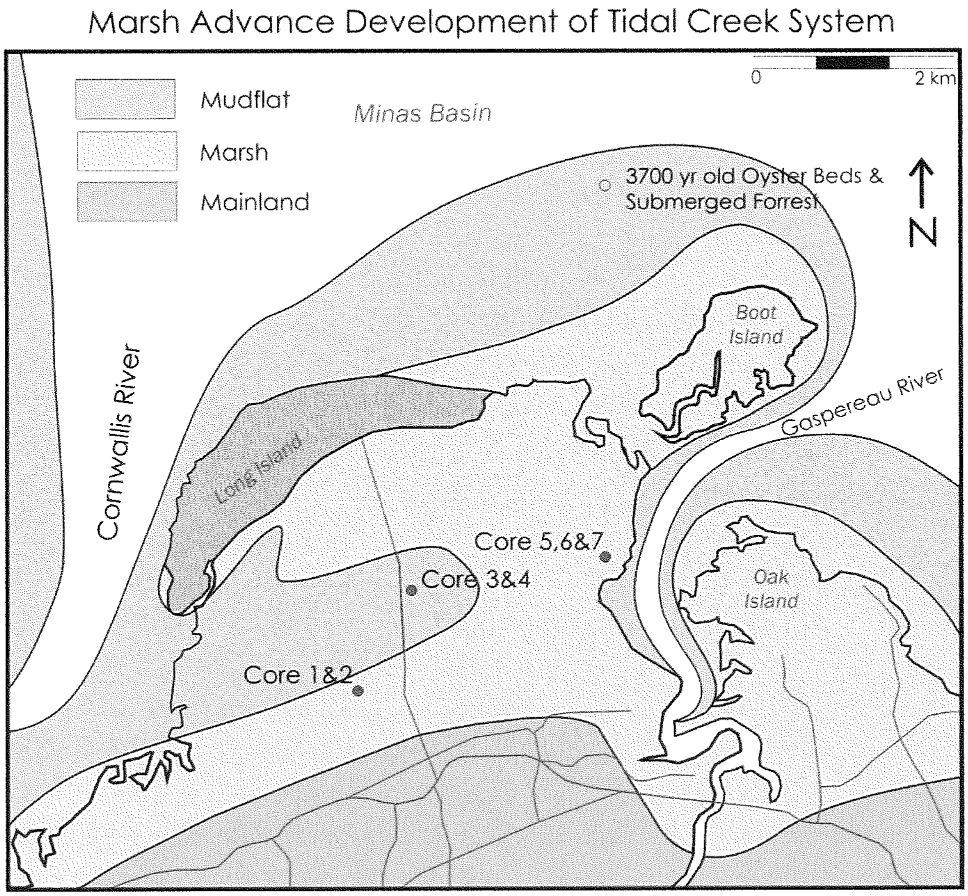


Figure 4.6: Illustration of Grand Pré as marsh re-advances based on interpretation of facies within the core collected in this study.

Sherman Bleakney (2004) provided evidence of a tidal creek adjacent to Long Island that troubled the Acadians throughout their history of dykeing. Also Starr's Point inter tidal creek has remained relatively the same with changes only to Cornwallis River (Sherman Bleakney, 2004). This can suggest that the area of mud flat covering Core 1,2,3 and 4 was no doubt an intertidal creek system identical to Starr's Point (Fig 4.7).

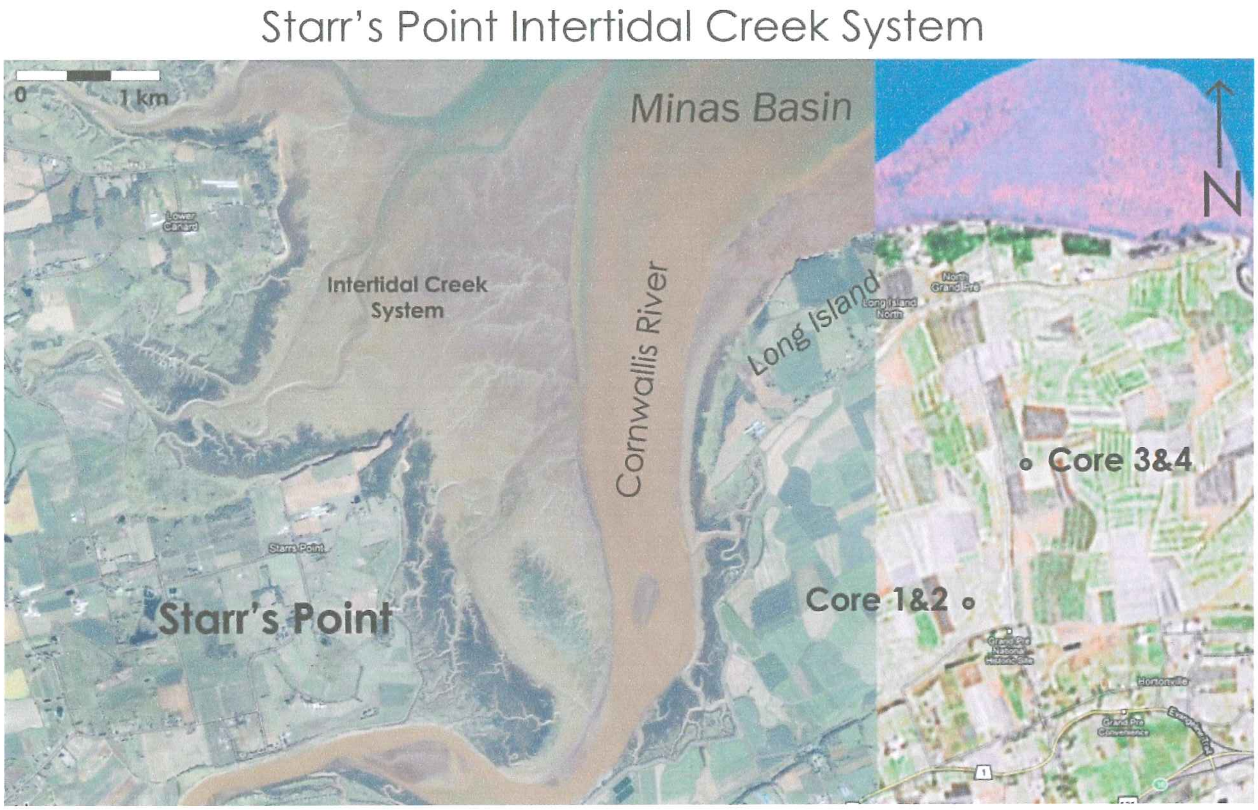


Figure 4.7: Aerial photograph of Starr's Point near Grand Pré showing the Starr's Point intertidal creek system (modified from Google Maps, 2010).

Shortly after the salt marsh was completely restored to the original state before the extreme local sea level rise. This can be determine due to the core samples 1,2,3 and 4 all display high marsh sitting stratigraphic above the mudflat.

The next change to the marsh would be the arrival of the Acadian settlers (Fig. 4.8). When the dyking stages were complete as mentions in chapter 1, this would change the landscape as it is view today. The dyke walls along the coastline caused heavy erosion due to the lack of sediment fallout and accommodation space and defines the present coastline. The full illustrated summary of the of 3000 years of coastal evolution at Grand Pre is in Appendix D.

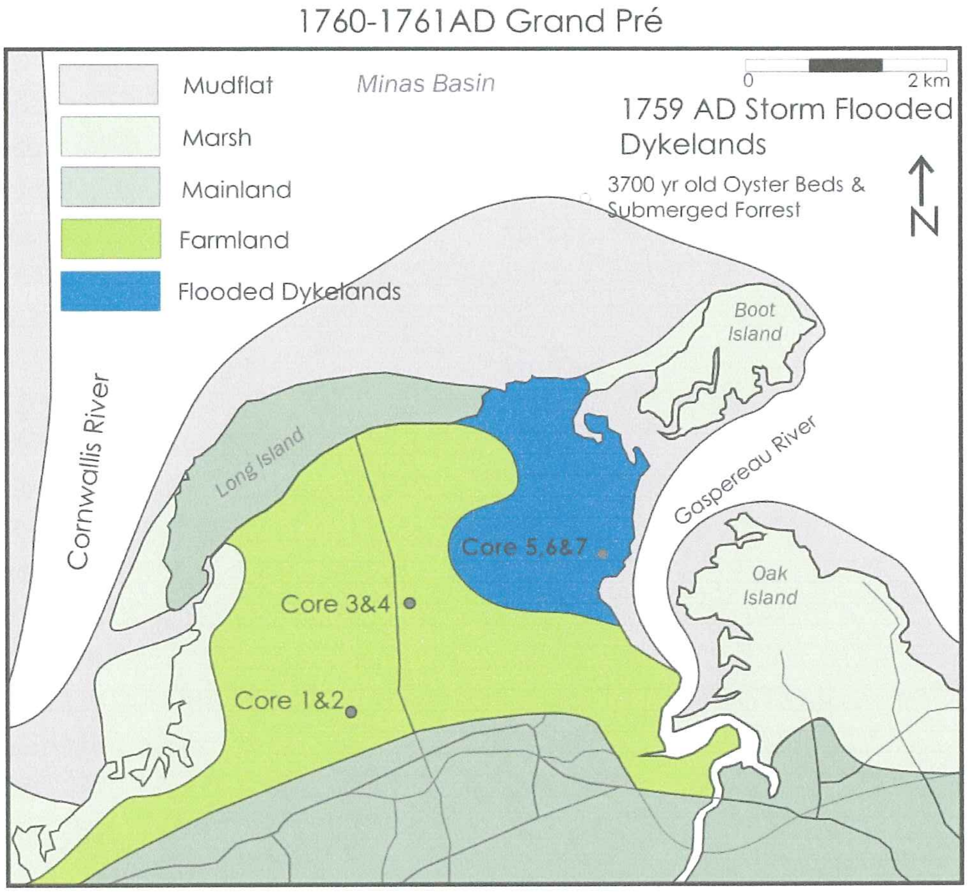


Figure 4.8: Illustration of Grand Pré as marsh in 1760 AD after the dykeing of the region by the Acadians. Shows a major flooding events caused by a storm in 1759 AD (Bleakney, 2004).

5.0 Conclusion and Recommendations

Although the original purpose of collecting cores from the Grand Pré dykeland was unsuccessful at locating archeological features, the information obtained from the cores was still a key component in determining the long-term history of the marsh. Using core descriptions, microfissils analysis and carbon-14 age dating a model for the evolution of the Grand Pre coastline has been developed. The data collected in Grand Pré indicates that the study area has been evolving over the last 3000 years. Studies from surrounding coastal salt marshes supports the data collected and the proposed coastal evolution. The area appears to have changed from marsh land to mudflat and back again, until the Acadian settlers defined the coastline that is seen today. This is the first study of its kind in Grand Pré and to develop a more accurate representation of past relative sea level rise events more data must be collected. For examples, more core samples, microfossil analysis, and sediment accumulation rates will help to provide a higher resolution model. This will provide a greater variety of studies able to be completed in this area including numerical models. Overall more data collection with help contribute to further studies about foraminifera zonation and relative sea level in the Minas Basin.

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APPENDIX A: Core Description Forms

Species Reference List:

Sp 1- *Trochammina inflata,*

Sp 2- *Tiphotrocha comprimata*

Sp 3- *Trochammina macrescens f. macrescens*

Sp 4- *Trochammina macrescens f. polystoma*

Sp 5- *Pseudothurammina limnetis*

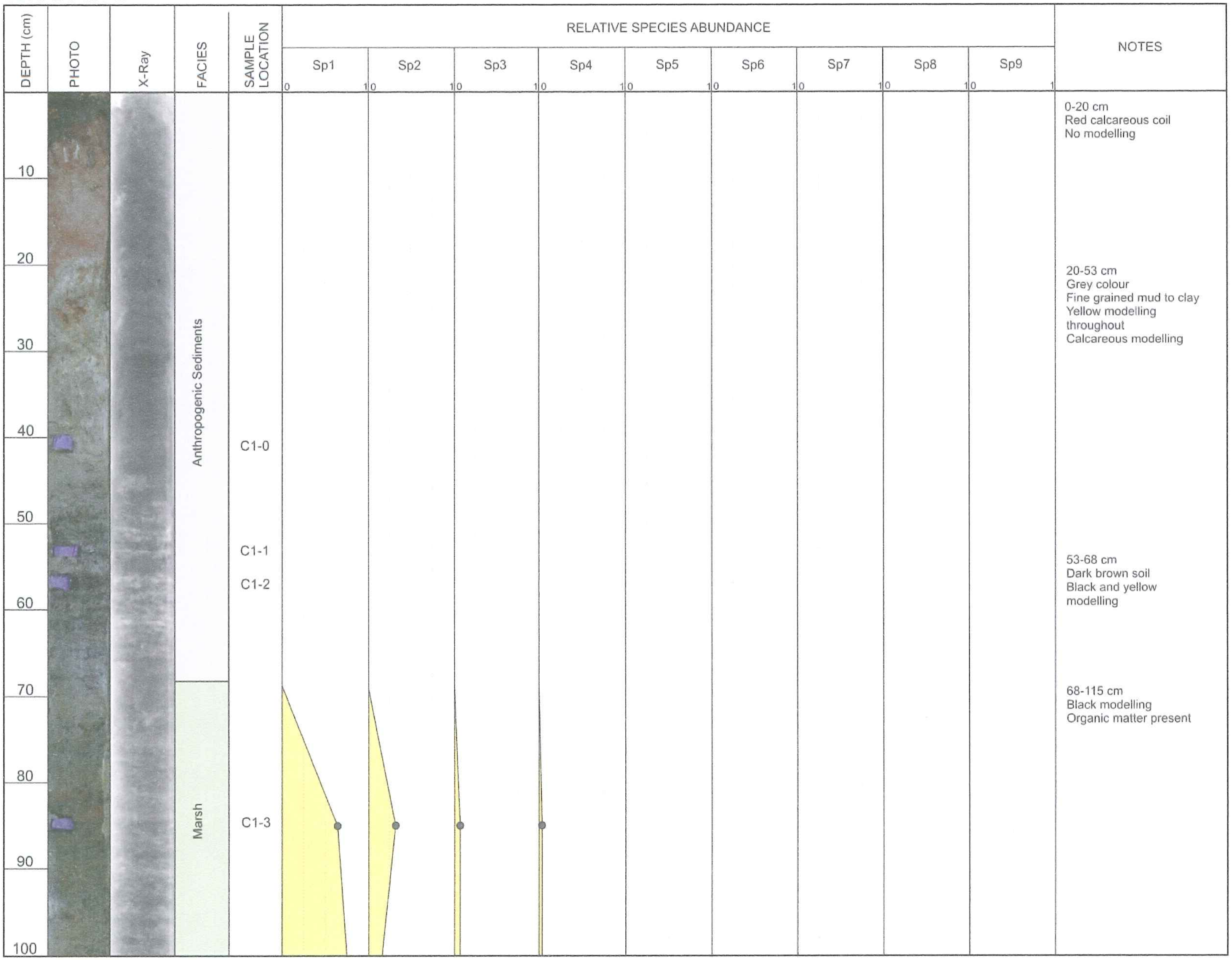
Sp 6- *Elphidium williansoni*

Sp 7- *Elphidium advenum*

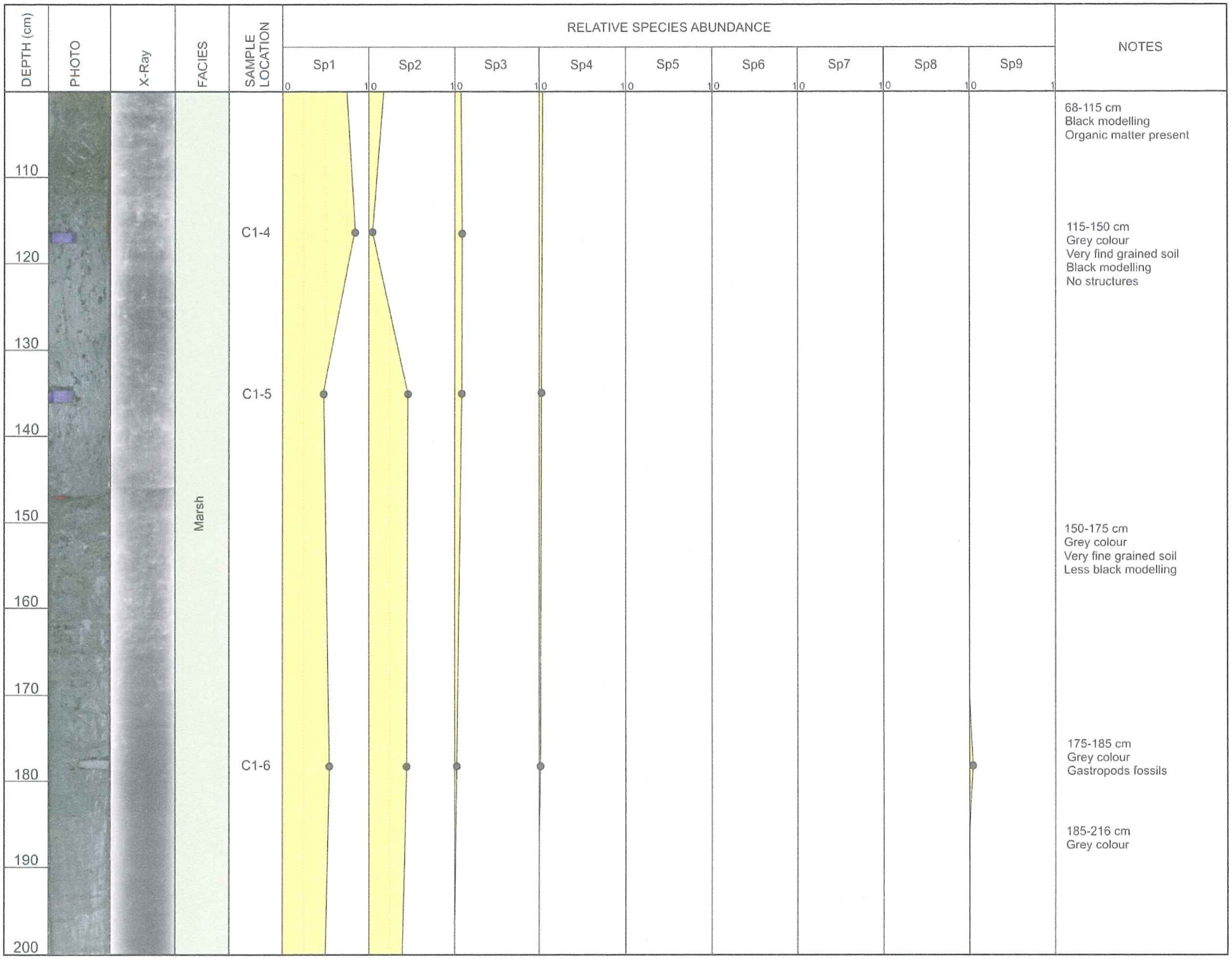
Sp 8- *Haynesina orbiculare*

Sp 9- *Arenoparella mexicana*

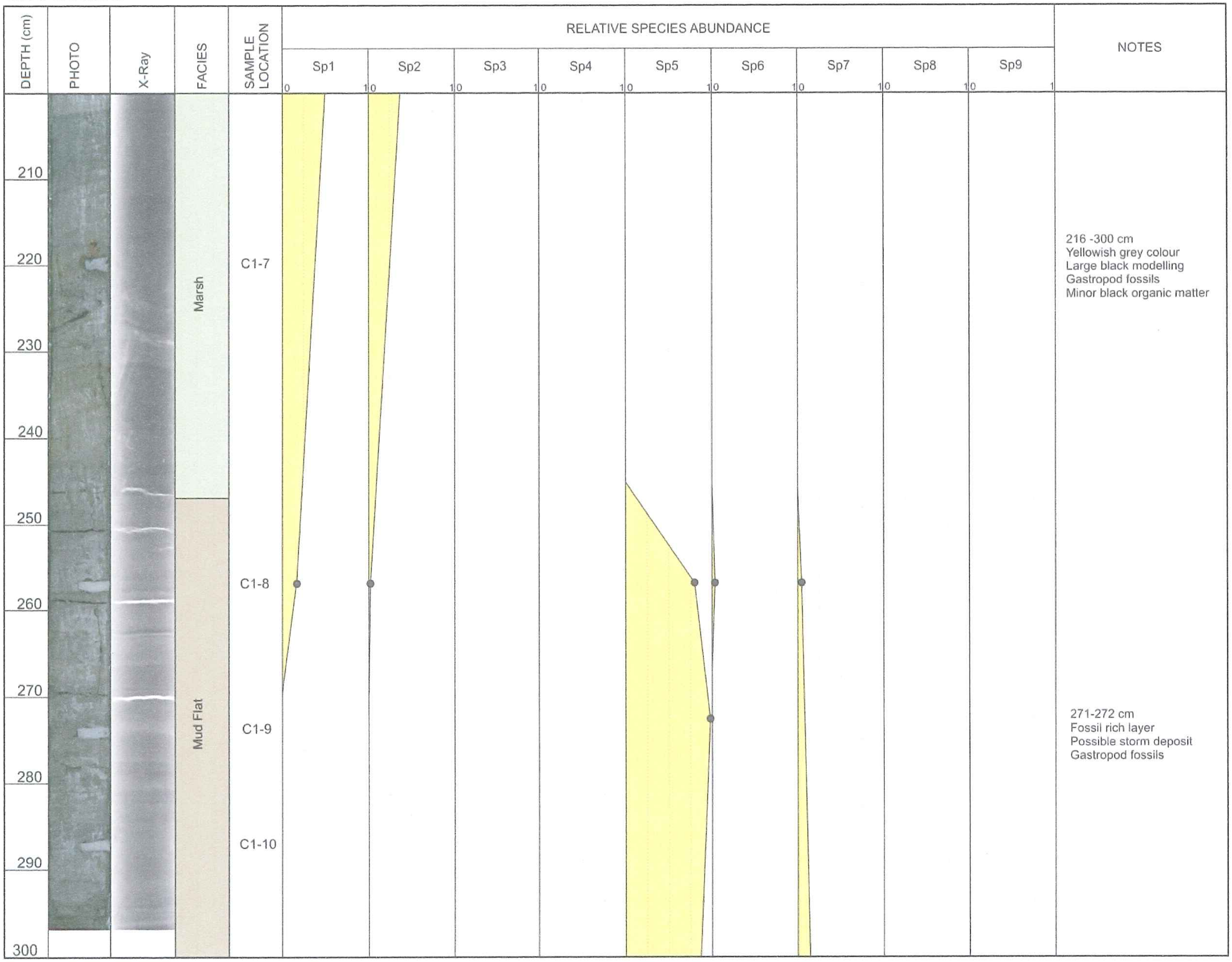
Core 1-Part 1


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
10
NOTES
10
20
30
40
50
60
70
80
90
100
Anthropogenic Sediments
Marsh
C1-0
C1-1
C1-2
C1-3
0-20 cm
Red calcareous coil
No modelling
20-53 cm
Grey colour
Fine grained mud to clay
Yellow modelling throughout
Calcareous modelling
53-68 cm
Dark brown soil
Black and yellow modelling
68-115 cm
Black modelling
Organic matter present

Core 1-Part 2


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
1
NOTES
110
120
130
140
150
160
170
180
190
200
Marsh
C1-4
C1-5
C1-6
68-115 cm
Black modelling
Organic matter present
115-150 cm
Grey colour
Very find grained soil
Black modelling
No structures
150-175 cm
Grey colour
Very fine grained soil
Less black modelling
175-185 cm
Grey colour
Gastropods fossils
185-216 cm
Grey colour

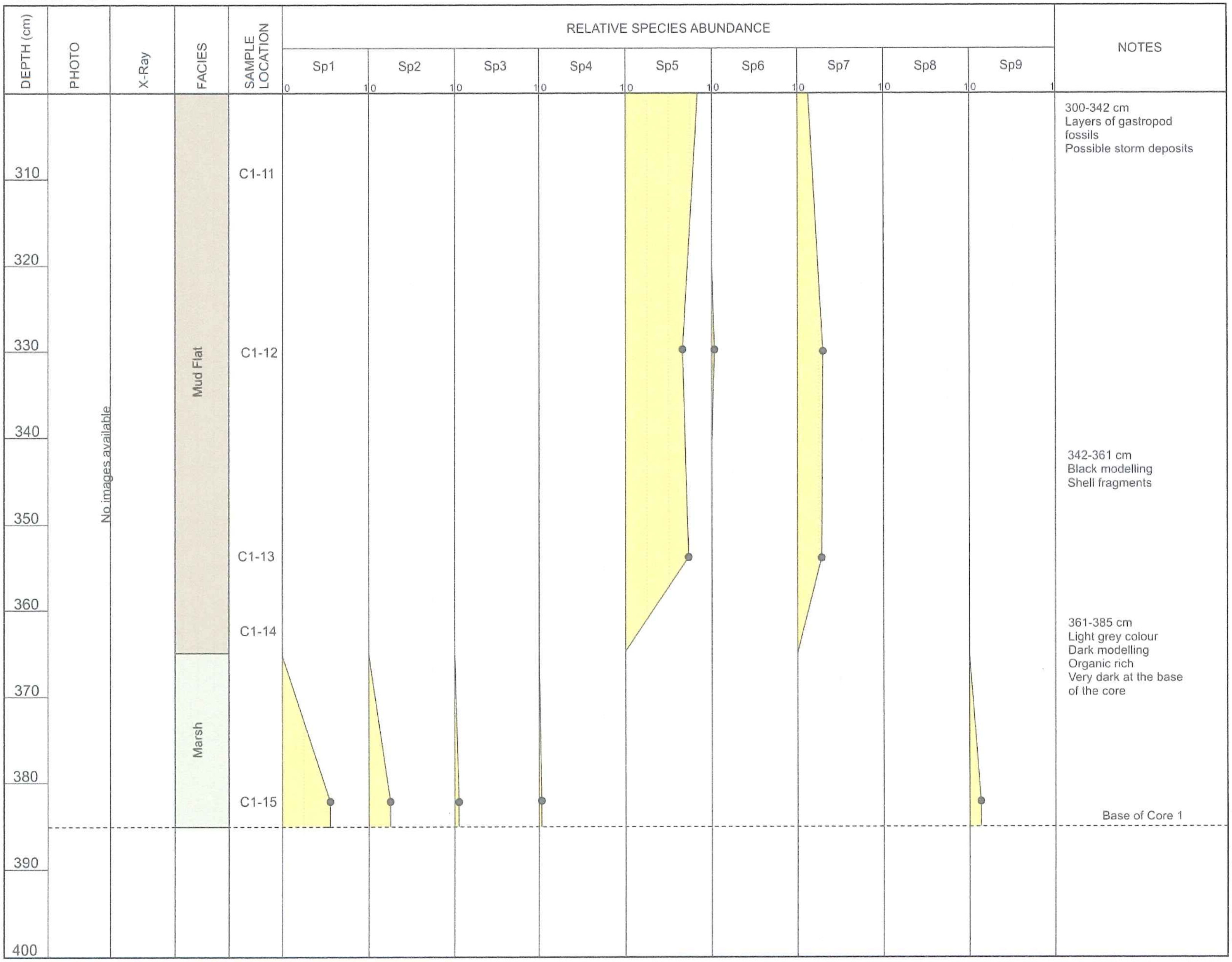
Core 1-Part 3



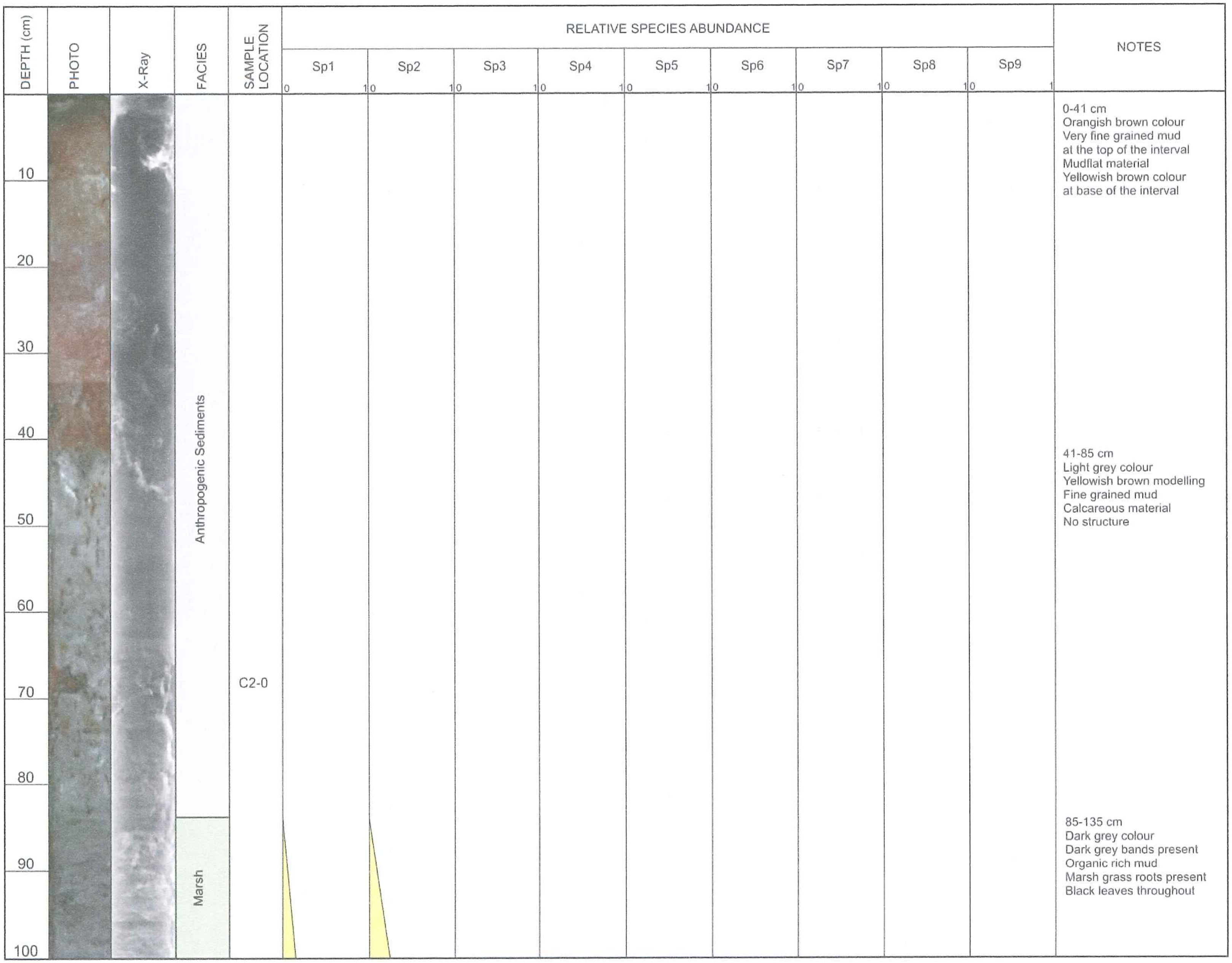
216 -300 cm
Yellowish grey colour
Large black modelling
Gastropod fossils
Minor black organic matter

271-272 cm
Fossil rich layer
Possible storm deposit
Gastropod fossils

Core 1-Part 4


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
10
1
NOTES
310
320
330
340
350
360
370
380
390
400
No images available
Mud Flat
Marsh
C1-11
C1-12
C1-13
C1-14
C1-15
300-342 cm
Layers of gastropod fossils
Possible storm deposits
342-361 cm
Black modelling
Shell fragments
361-385 cm
Light grey colour
Dark modelling
Organic rich
Very dark at the base of the core
Base of Core 1

Core 2-Part 1

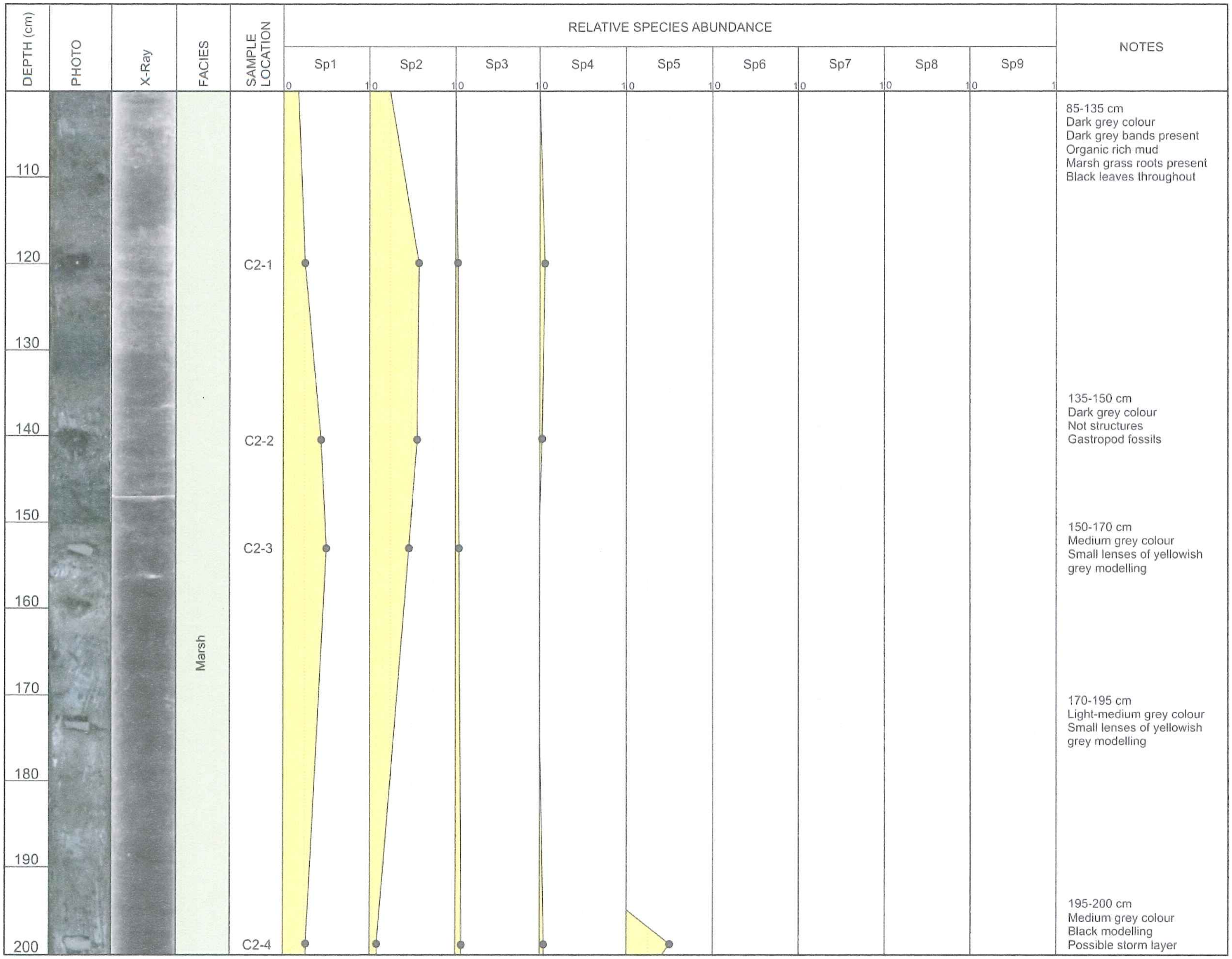


0-41 cm
Orangish brown colour
Very fine grained mud
at the top of the interval
Mudflat material
Yellowish brown colour
at base of the interval

41-85 cm
Light grey colour
Yellowish brown modelling
Fine grained mud
Calcareous material
No structure

85-135 cm
Dark grey colour
Dark grey bands present
Organic rich mud
Marsh grass roots present
Black leaves throughout

Core 2-Part 2



85-135 cm
Dark grey colour
Dark grey bands present
Organic rich mud
Marsh grass roots present
Black leaves throughout

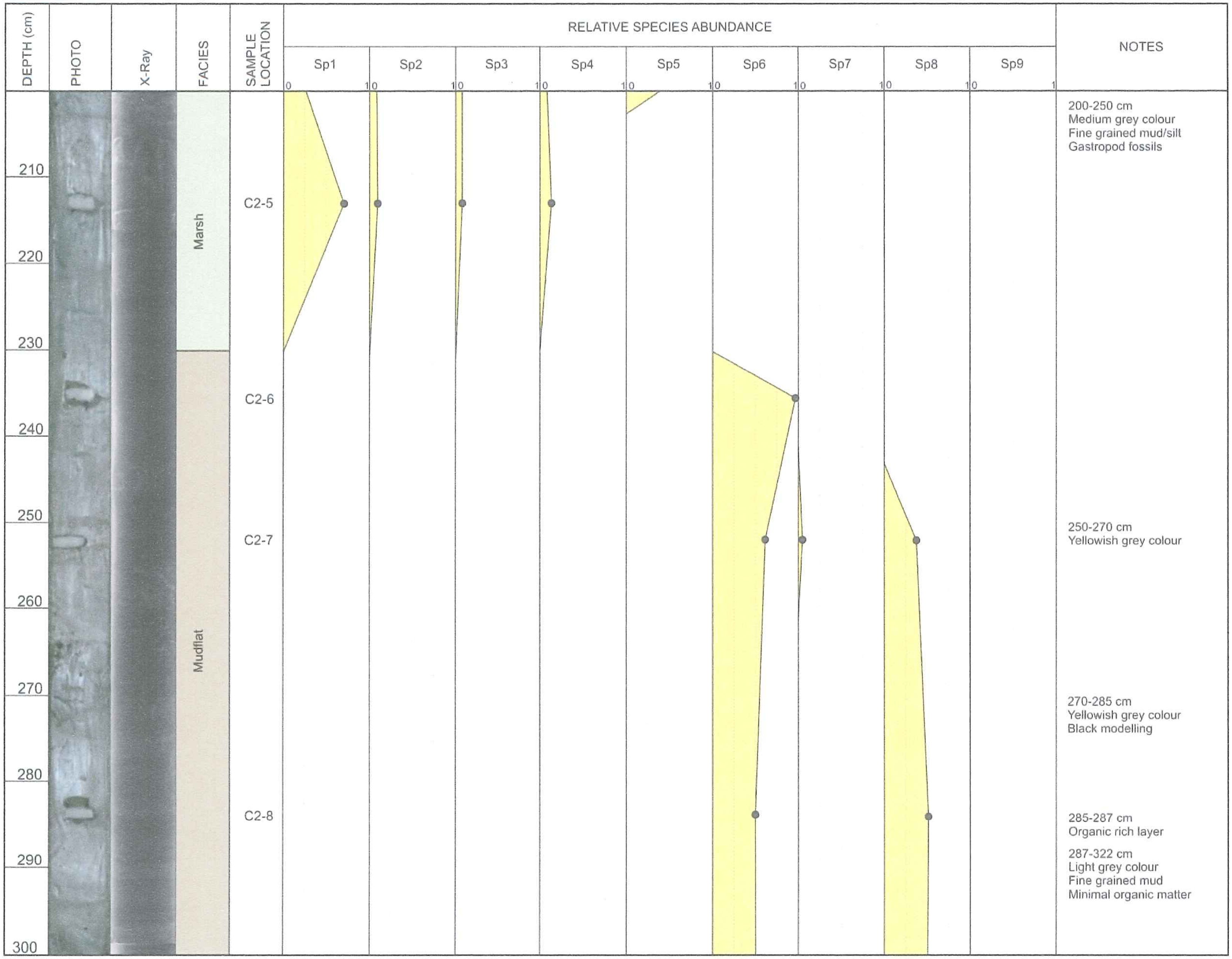
135-150 cm
Dark grey colour
Not structures
Gastropod fossils

150-170 cm
Medium grey colour
Small lenses of yellowish grey modelling

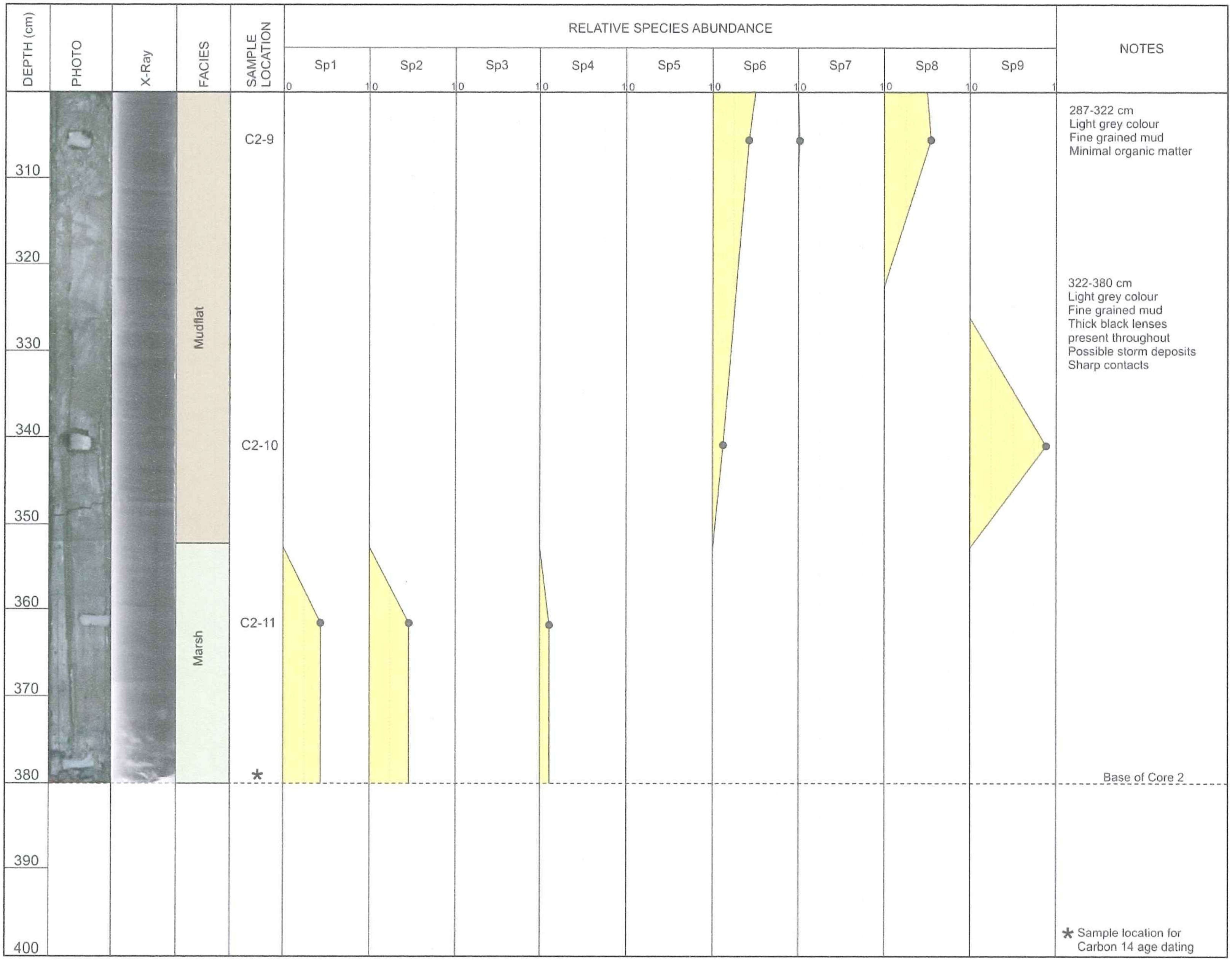
170-195 cm
Light-medium grey colour
Small lenses of yellowish grey modelling

195-200 cm
Medium grey colour
Black modelling
Possible storm layer

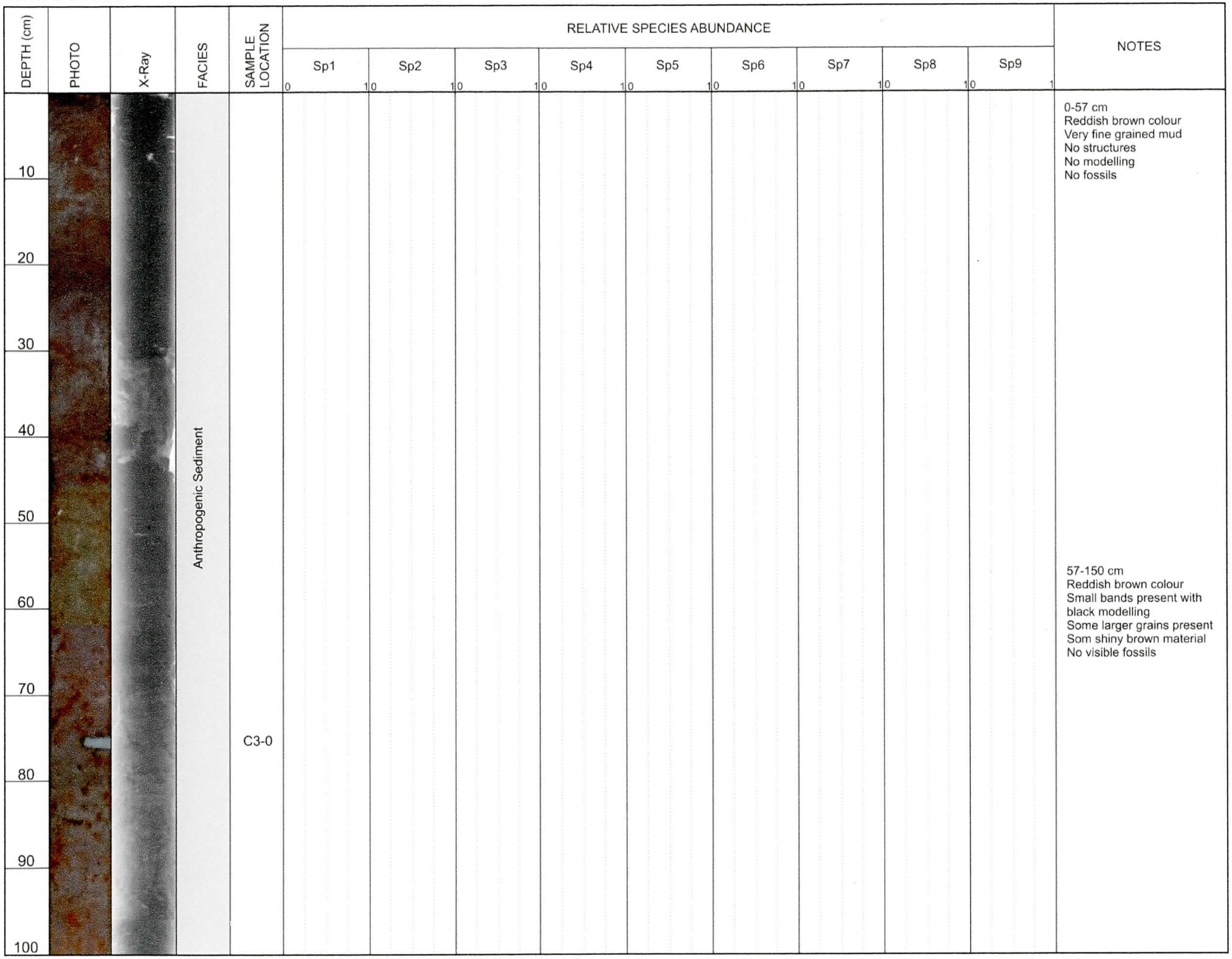
Core 2-Part 3


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
NOTES
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
10
10
10
10
10
10
10
10
1
210
220
230
240
250
260
270
280
290
300
Marsh
Mudflat
C2-5
C2-6
C2-7
C2-8
200-250 cm
Medium grey colour
Fine grained mud/silt
Gastropod fossils
250-270 cm
Yellowish grey colour
270-285 cm
Yellowish grey colour
Black modelling
285-287 cm
Organic rich layer
287-322 cm
Light grey colour
Fine grained mud
Minimal organic matter

Core 2-Part 4


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
NOTES
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
10
1
310
320
330
340
350
360
370
380
390
400
Mudflat
Marsh
C2-9
C2-10
C2-11
*
287-322 cm
Light grey colour
Fine grained mud
Minimal organic matter
322-380 cm
Light grey colour
Fine grained mud
Thick black lenses
present throughout
Possible storm deposits
Sharp contacts
Base of Core 2
* Sample location for
Carbon 14 age dating

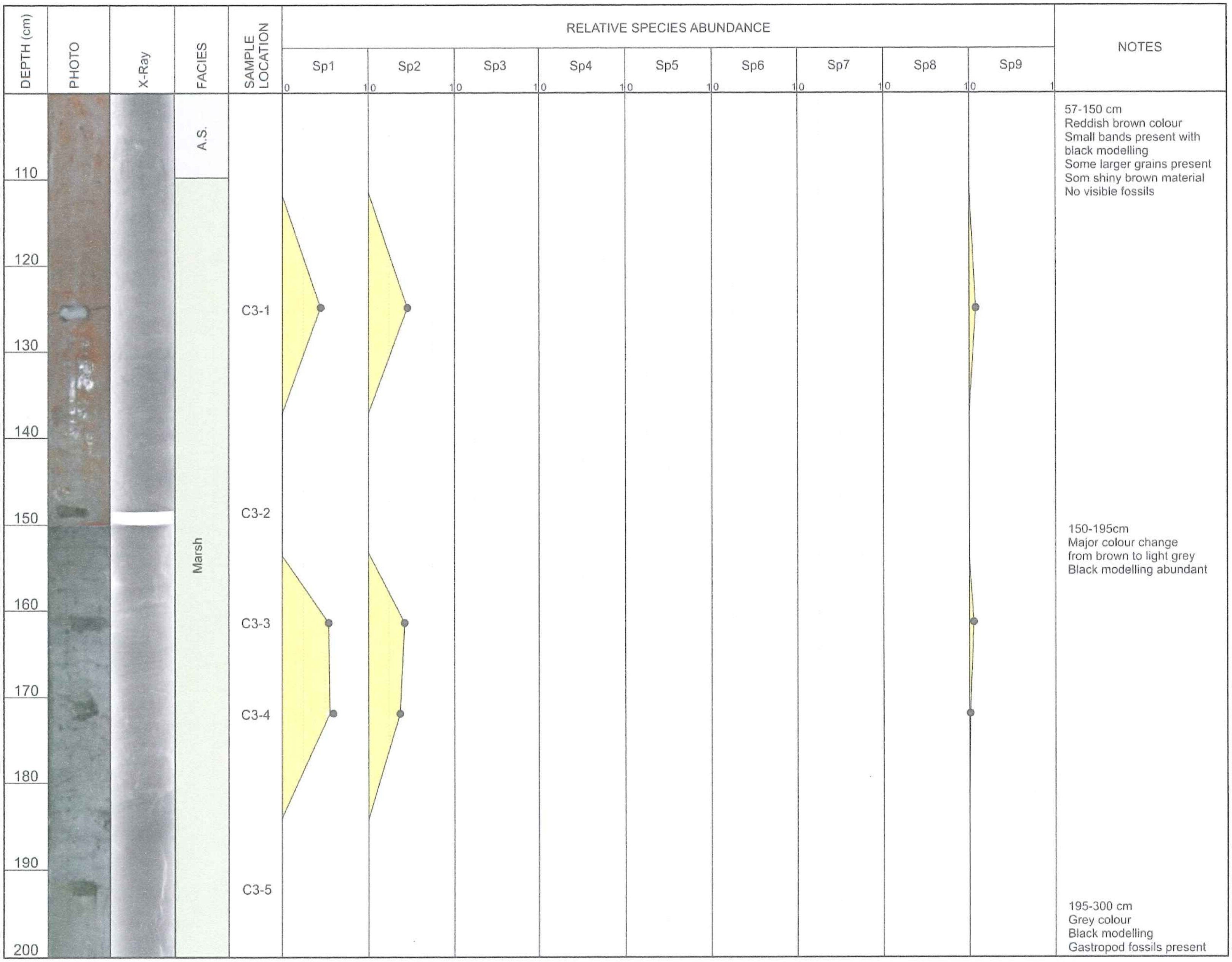
Core 3-Part 1



0-57 cm
Reddish brown colour
Very fine grained mud
No structures
No modelling
No fossils

57-150 cm
Reddish brown colour
Small bands present with
black modelling
Some larger grains present
Som shiny brown material
No visible fossils

Core 3-Part 2

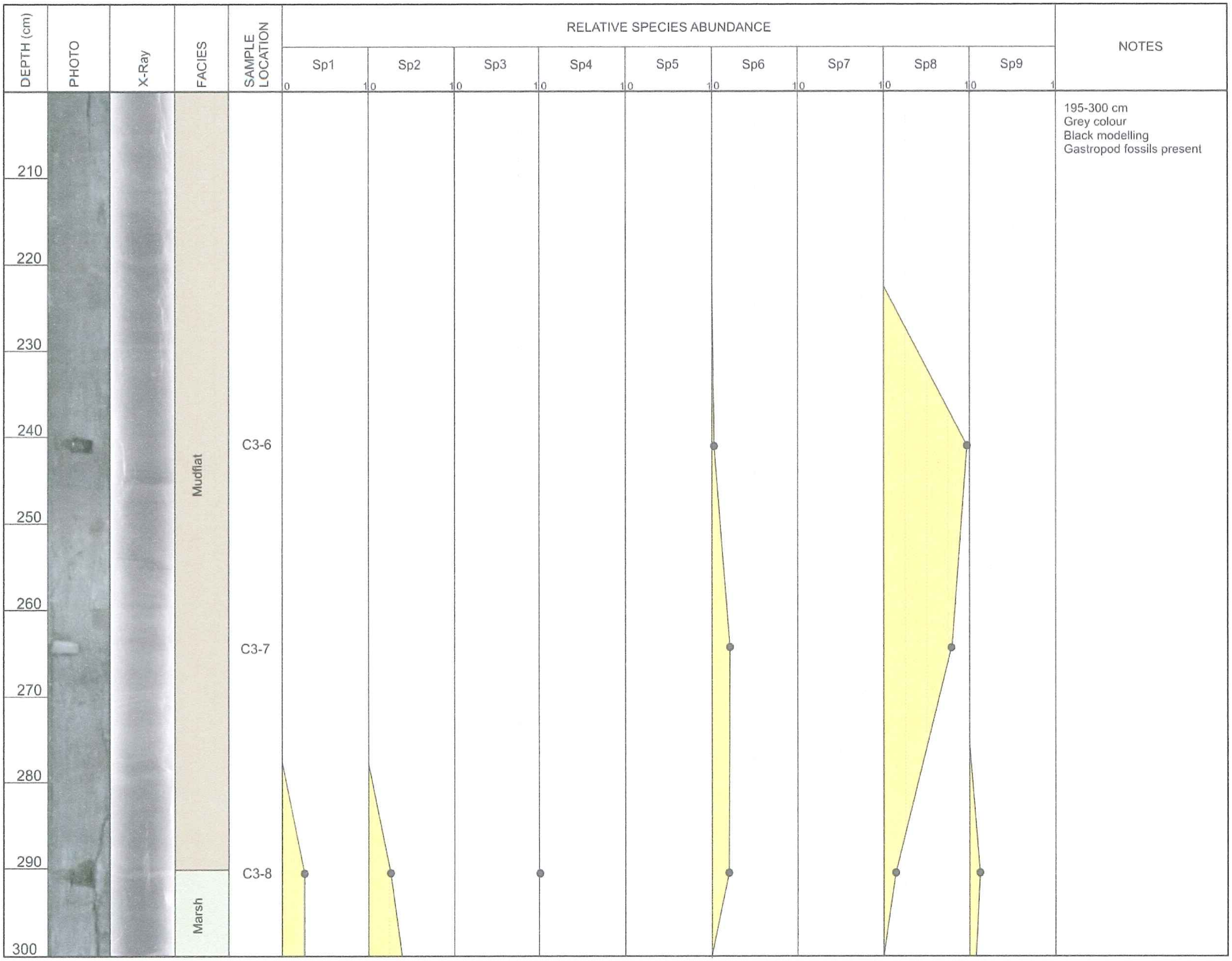


57-150 cm
Reddish brown colour
Small bands present with black modelling
Some larger grains present
Som shiny brown material
No visible fossils

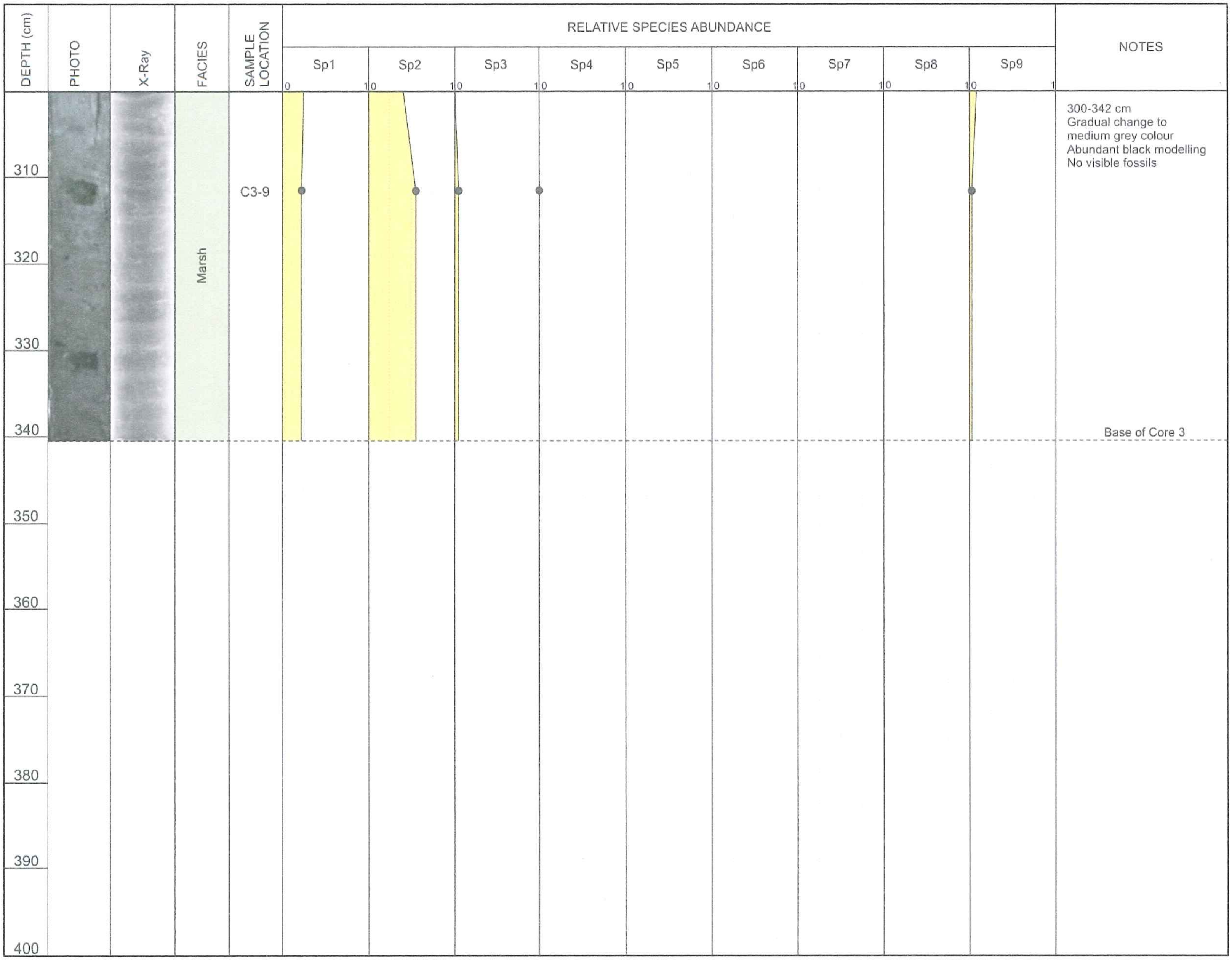
150-195cm
Major colour change from brown to light grey
Black modelling abundant

195-300 cm
Grey colour
Black modelling
Gastropod fossils present

Core 3-Part 3


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
NOTES
0
10
1
210
220
230
240
250
260
270
280
290
300
Mudflat
Marsh
C3-6
C3-7
C3-8
195-300 cm
Grey colour
Black modelling
Gastropod fossils present

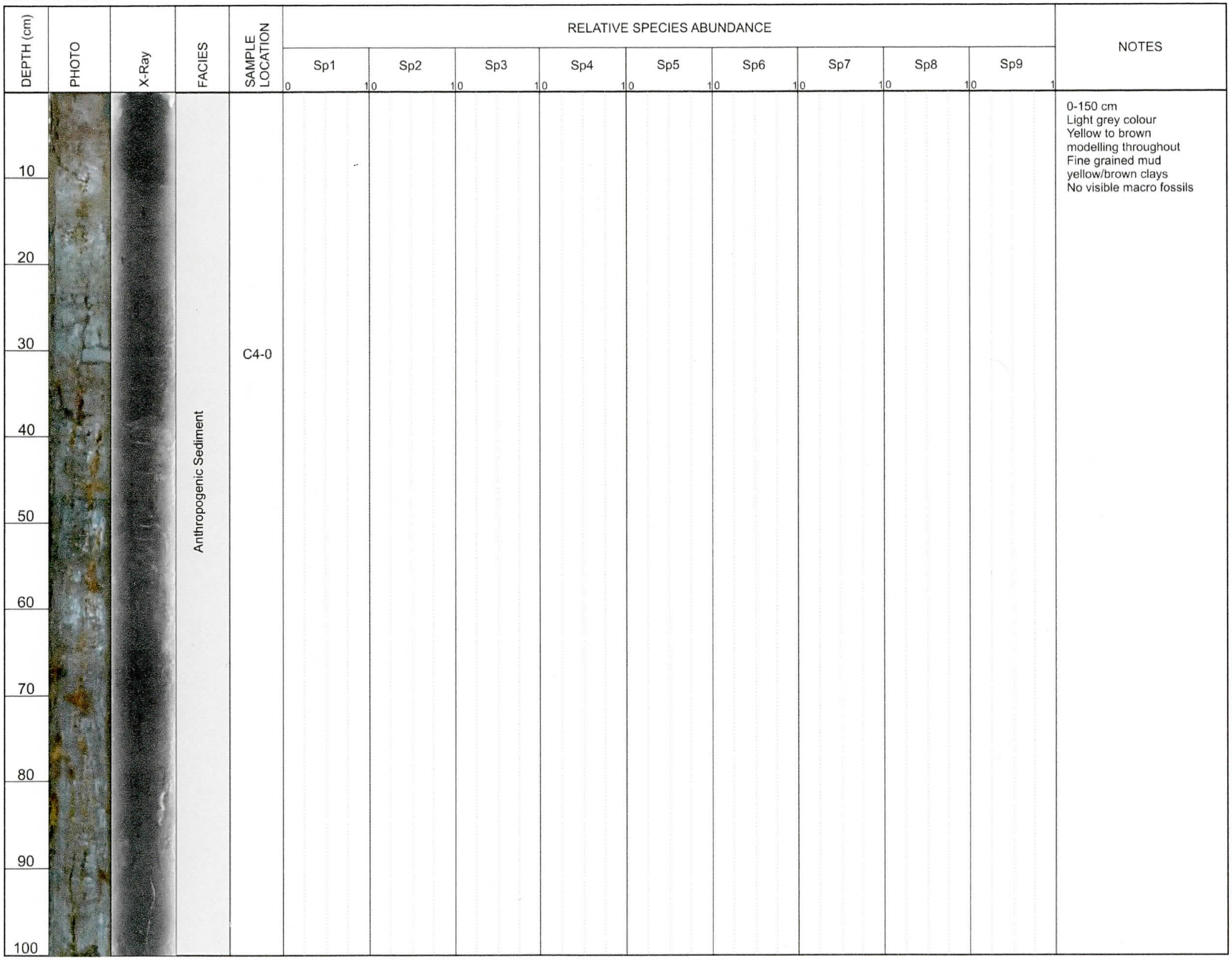
Core 3-Part 4



300-342 cm
Gradual change to medium grey colour
Abundant black modelling
No visible fossils

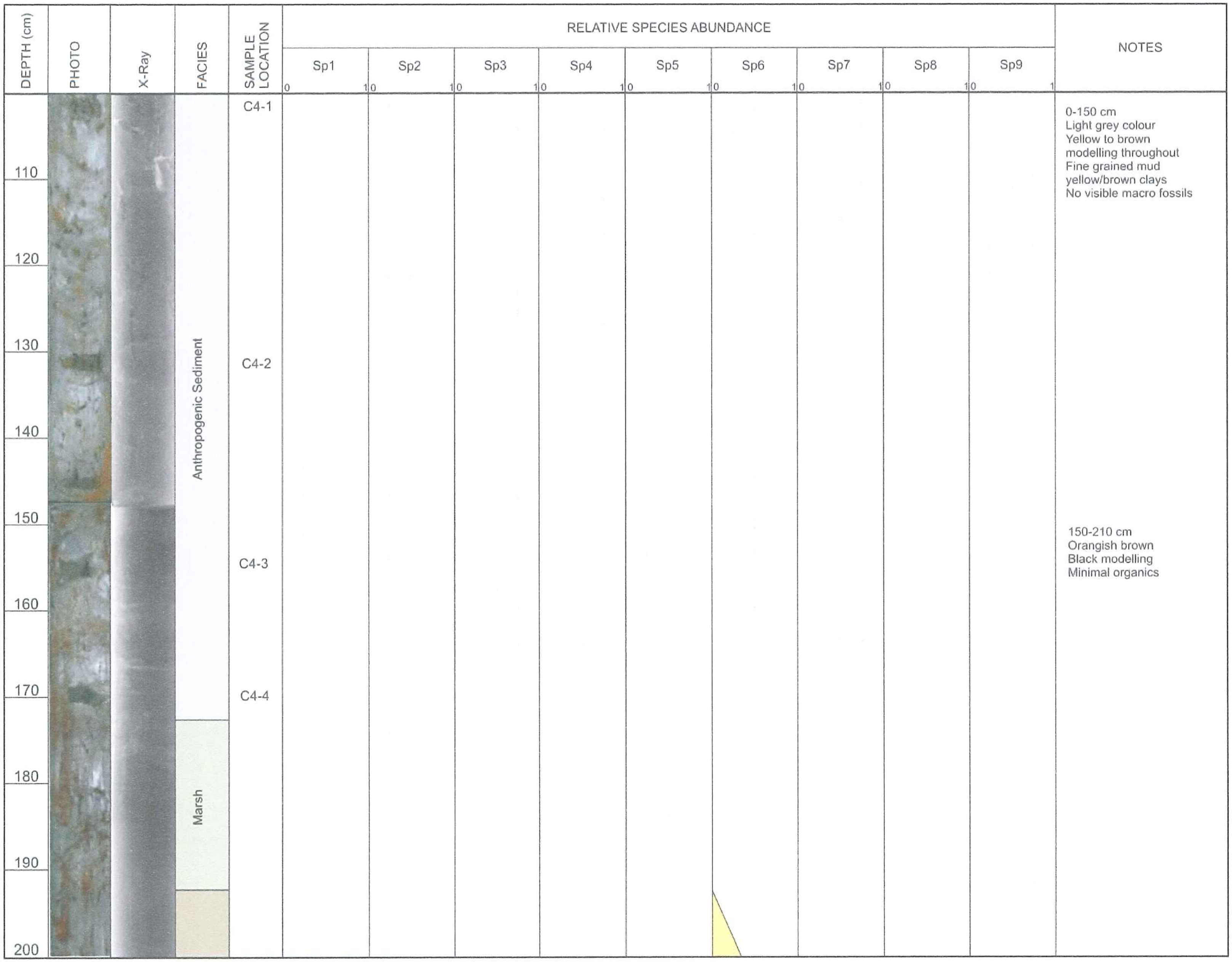
Base of Core 3

Core 4-Part 1



0-150 cm
Light grey colour
Yellow to brown
modelling throughout
Fine grained mud
yellow/brown clays
No visible macro fossils

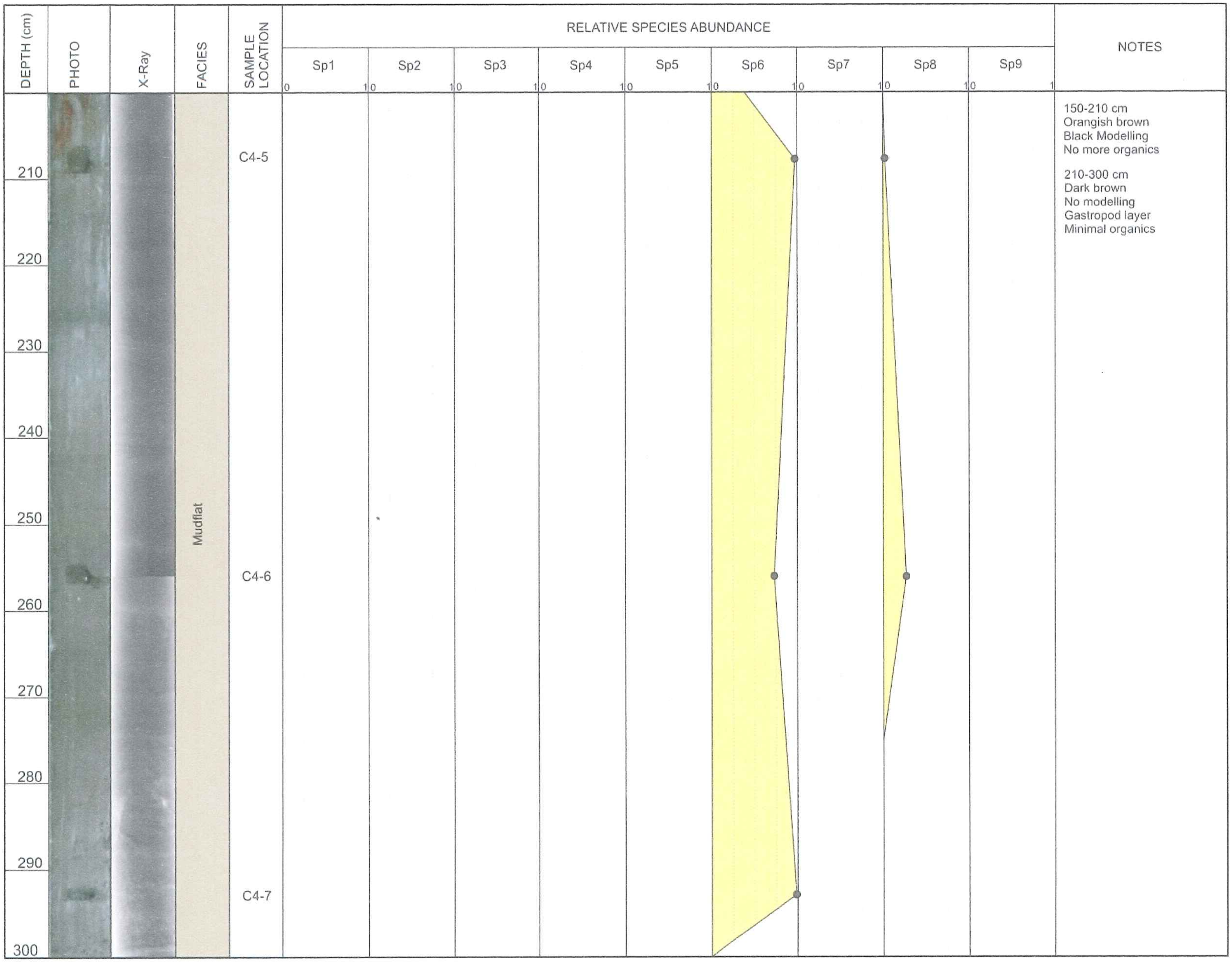
Core 4-Part 2



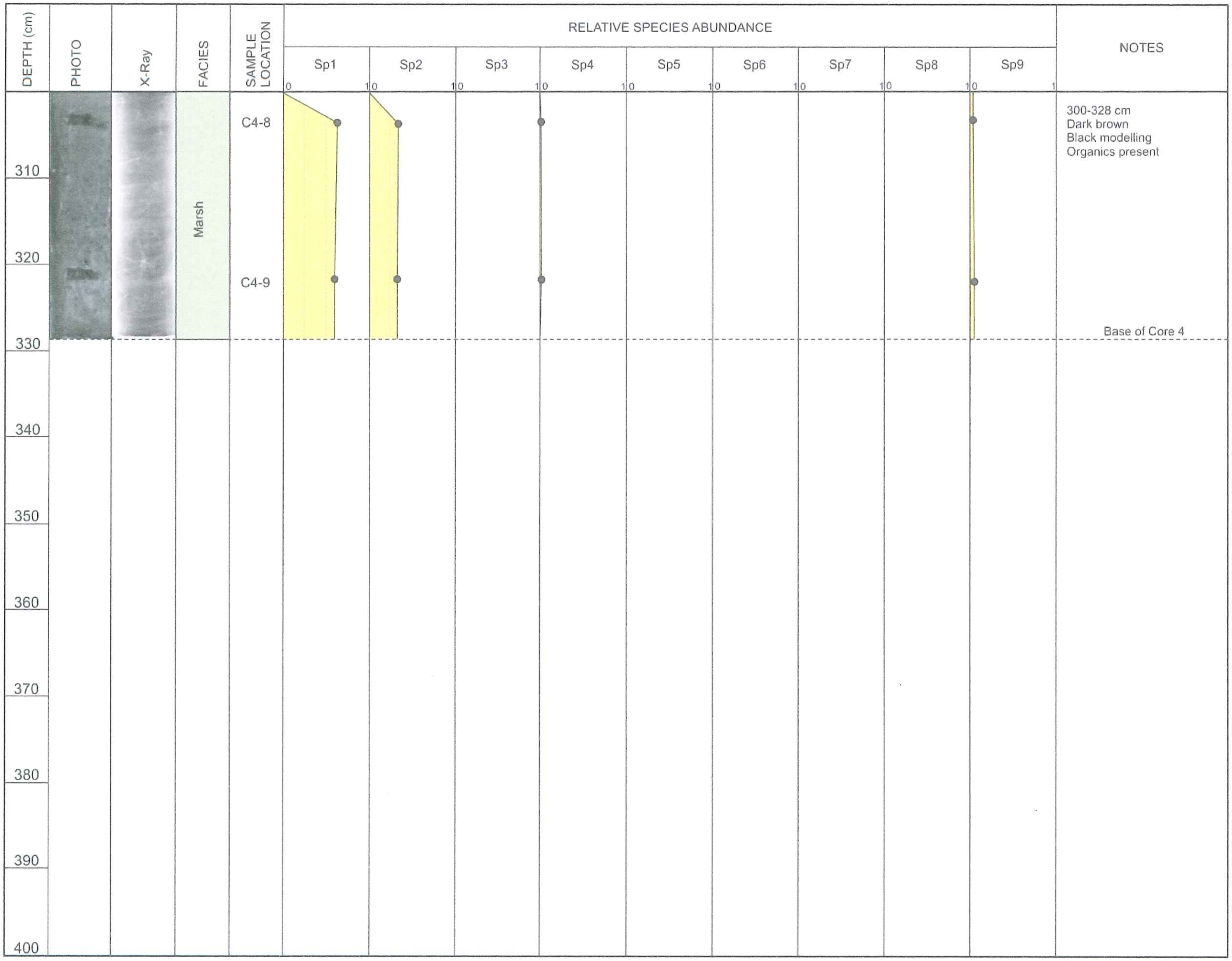
0-150 cm
Light grey colour
Yellow to brown
modelling throughout
Fine grained mud
yellow/brown clays
No visible macro fossils

150-210 cm
Orangish brown
Black modelling
Minimal organics

Core 4-Part 3


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
NOTES
0
1
210
220
230
240
250
260
270
280
290
300
Mudflat
C4-5
C4-6
C4-7
150-210 cm
Orangish brown
Black Modelling
No more organics
210-300 cm
Dark brown
No modelling
Gastropod layer
Minimal organics

Core 4-Part 4


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
NOTES
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
1
310
320
330
340
350
360
370
380
390
400
Marsh
C4-8
C4-9
300-328 cm
Dark brown
Black modelling
Organics present
Base of Core 4

Core 5-Part 1

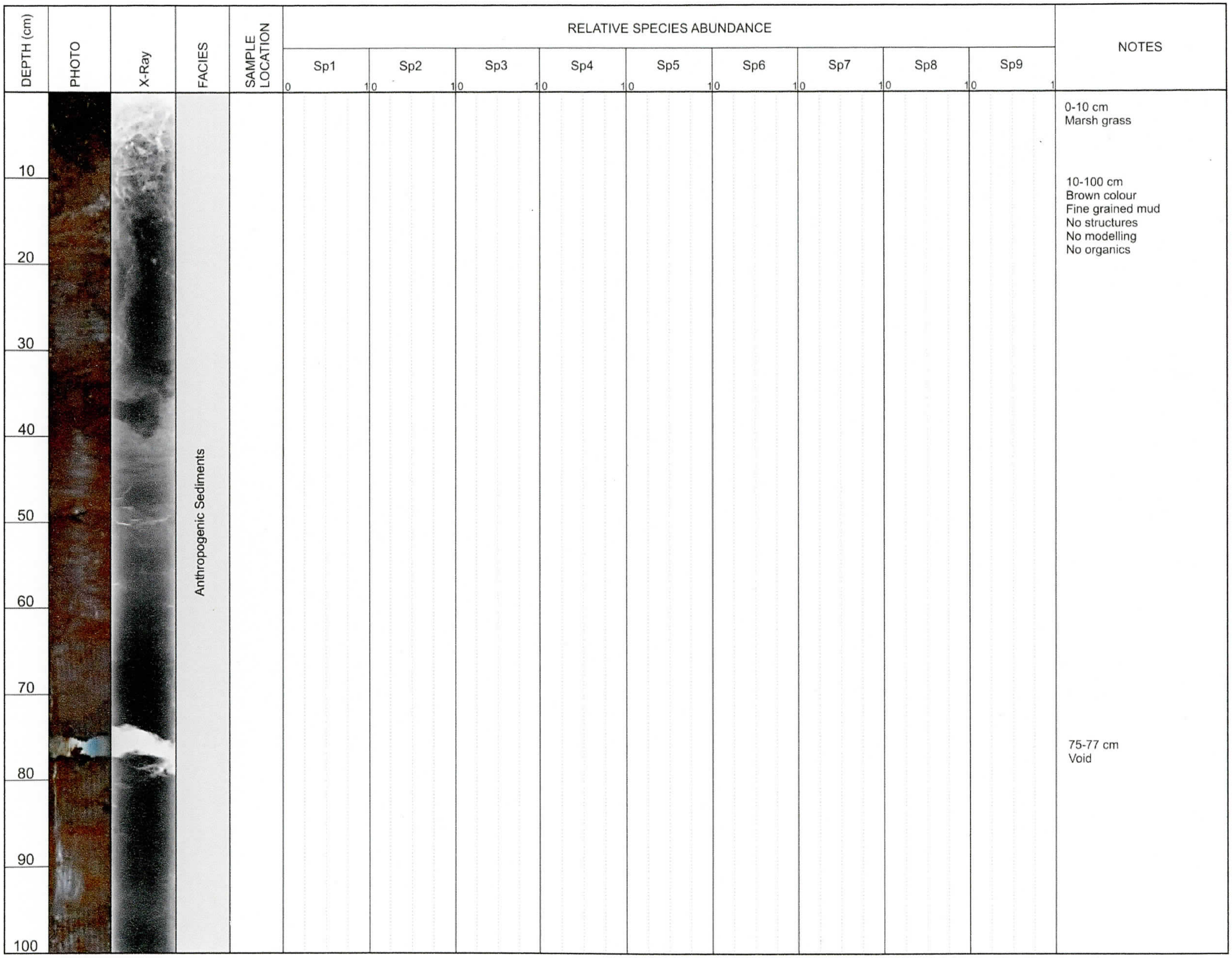

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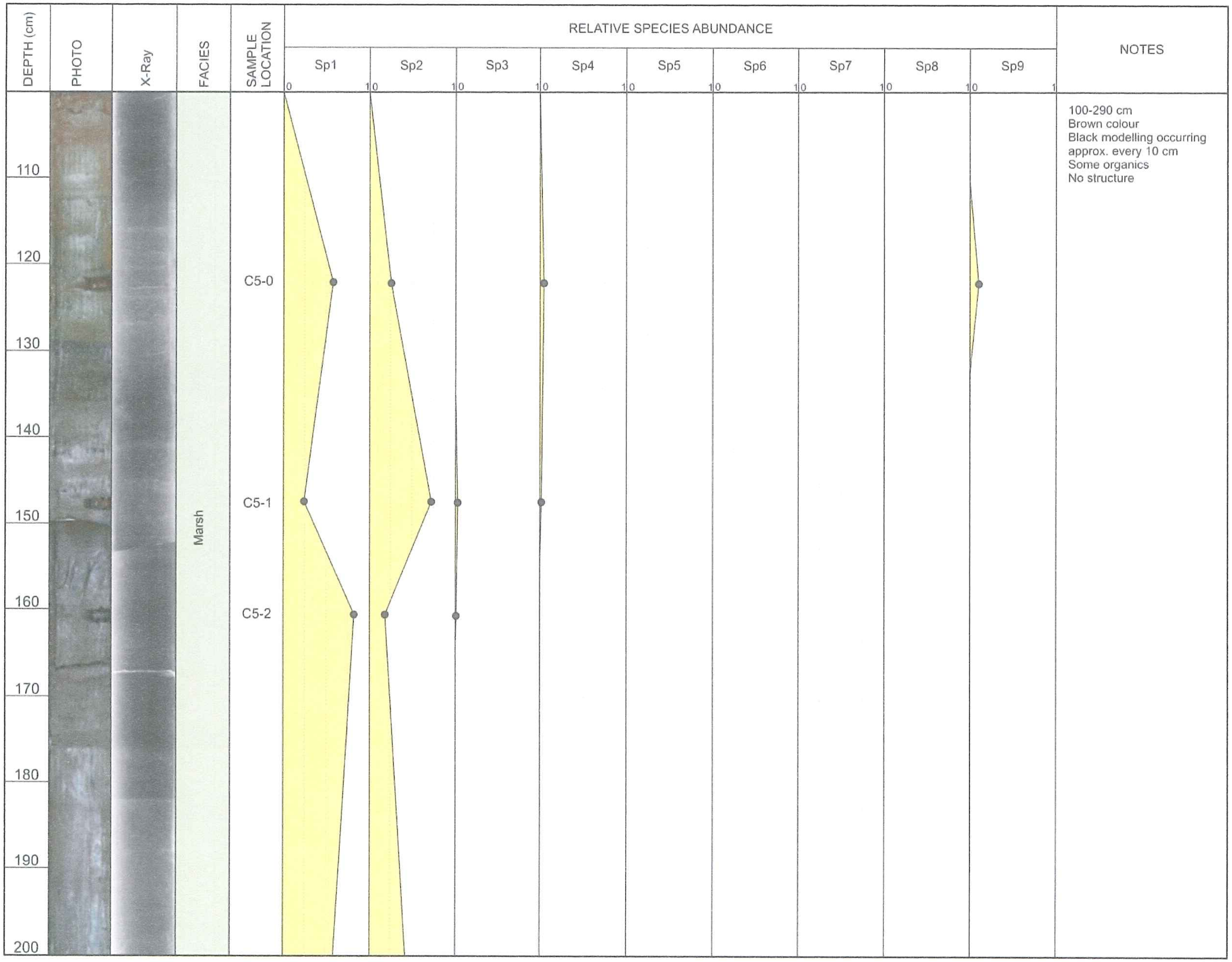
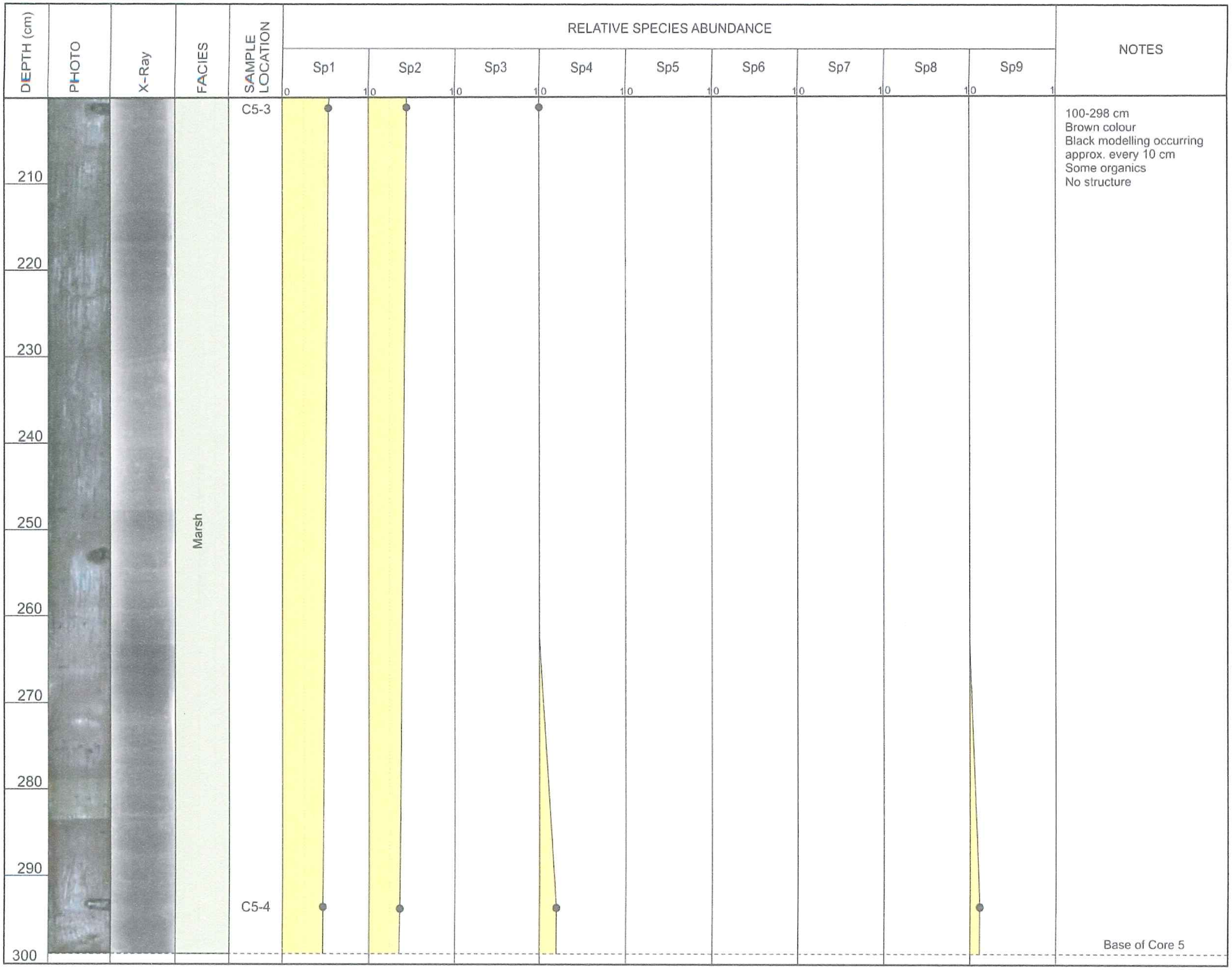
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
1
NOTES
10
20
30
40
50
60
70
80
90
100
Anthropogenic Sediments
0-10 cm
Marsh grass
10-100 cm
Brown colour
Fine grained mud
No structures
No modelling
No organics
75-77 cm
Void

Core 5-Part 2

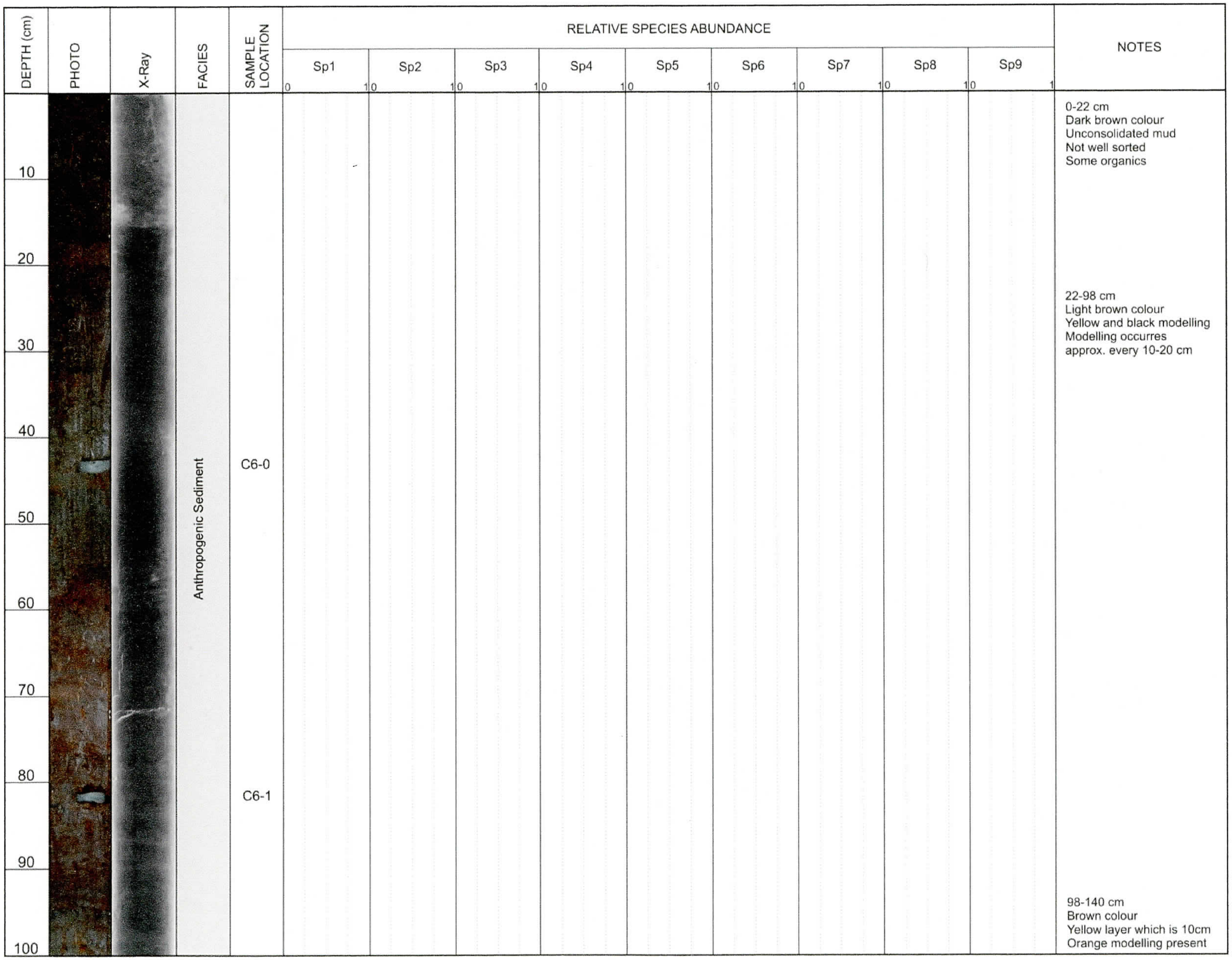

DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
NOTES
0
10
1
110
120
130
140
150
160
170
180
190
200
Marsh
C5-0
C5-1
C5-2
100-290 cm
Brown colour
Black modelling occurring
approx. every 10 cm
Some organics
No structure

Core 5-Part 3



100-298 cm
Brown colour
Black modelling occurring approx. every 10 cm
Some organics
No structure

Core 6-Part 1

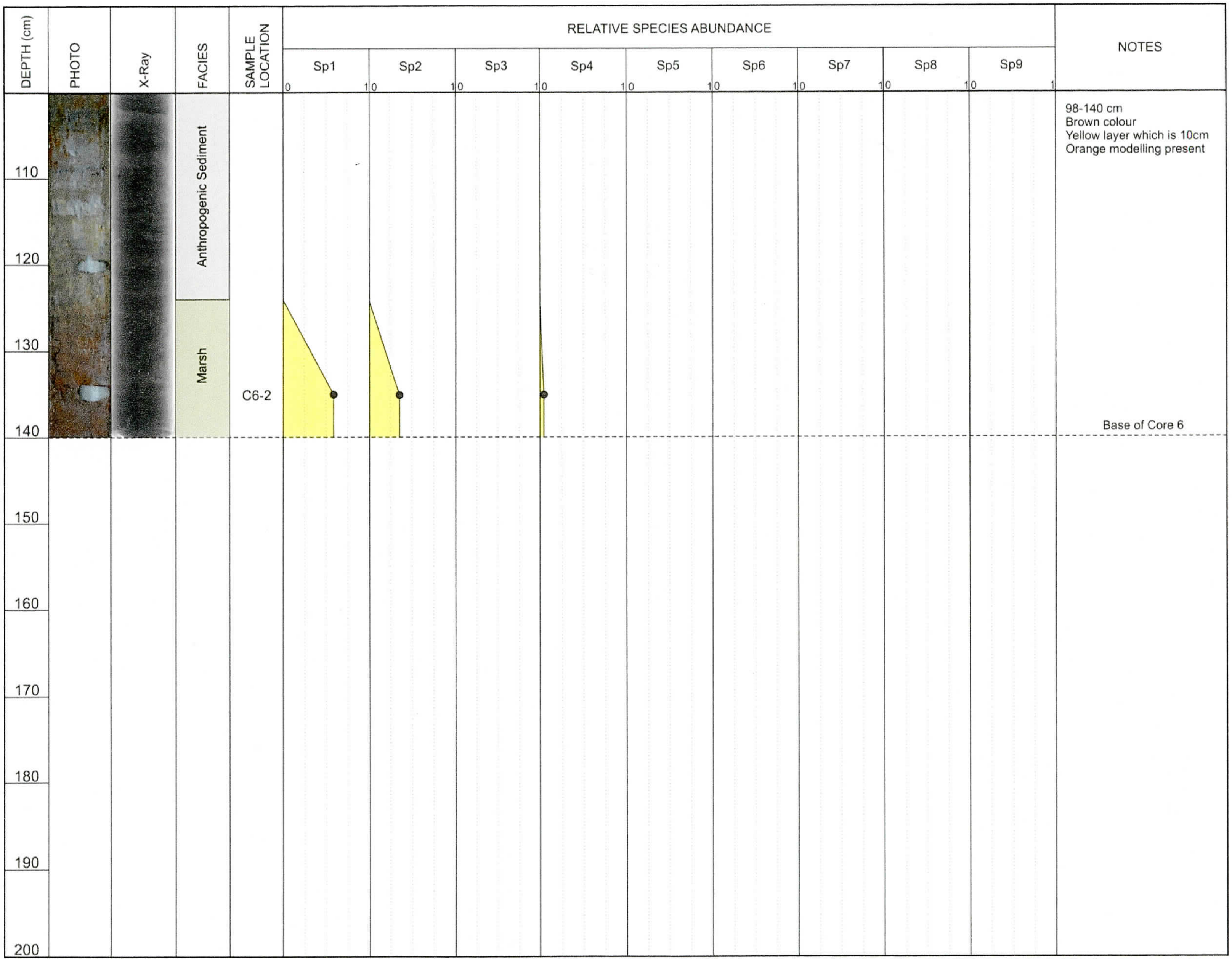


0-22 cm
Dark brown colour
Unconsolidated mud
Not well sorted
Some organics

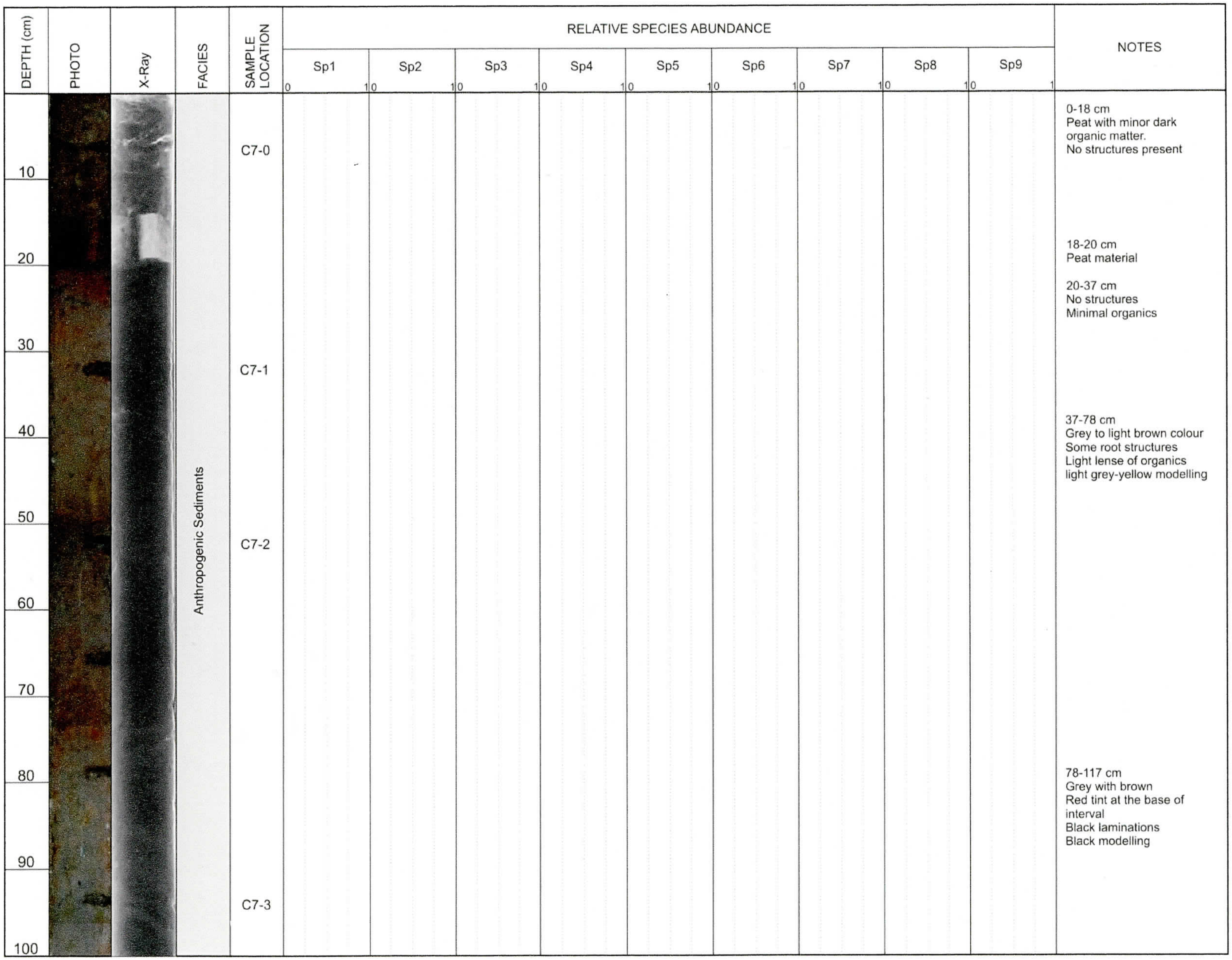
22-98 cm
Light brown colour
Yellow and black modelling
Modelling occurres
approx. every 10-20 cm

98-140 cm
Brown colour
Yellow layer which is 10cm
Orange modelling present

Core 6-Part 2


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
NOTES
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
1
110
120
130
140
150
160
170
180
190
200
Anthropogenic Sediment
Marsh
C6-2
98-140 cm
Brown colour
Yellow layer which is 10cm
Orange modelling present
Base of Core 6

Core 7-Part 1



0-18 cm
Peat with minor dark organic matter.
No structures present

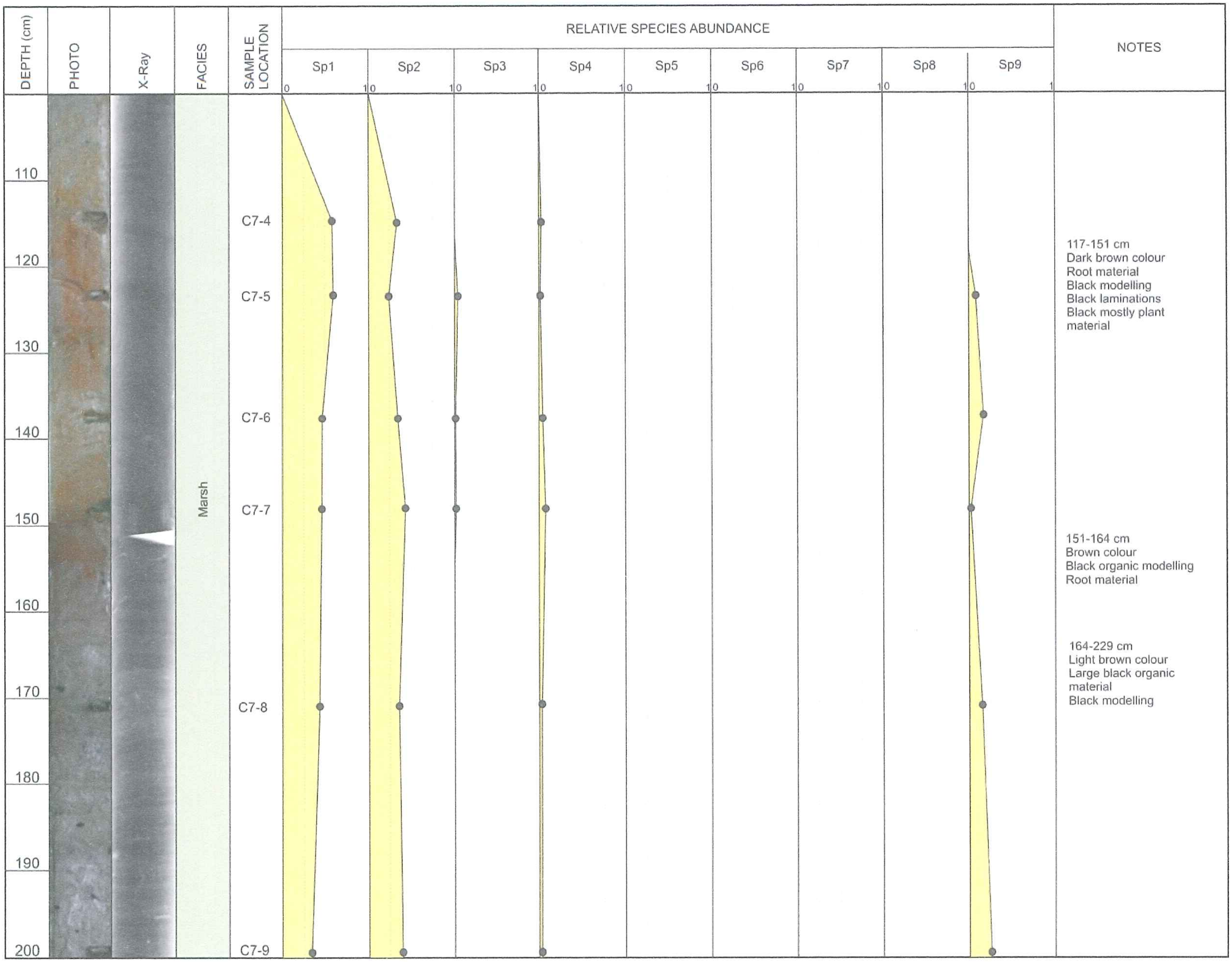
18-20 cm
Peat material

20-37 cm
No structures
Minimal organics

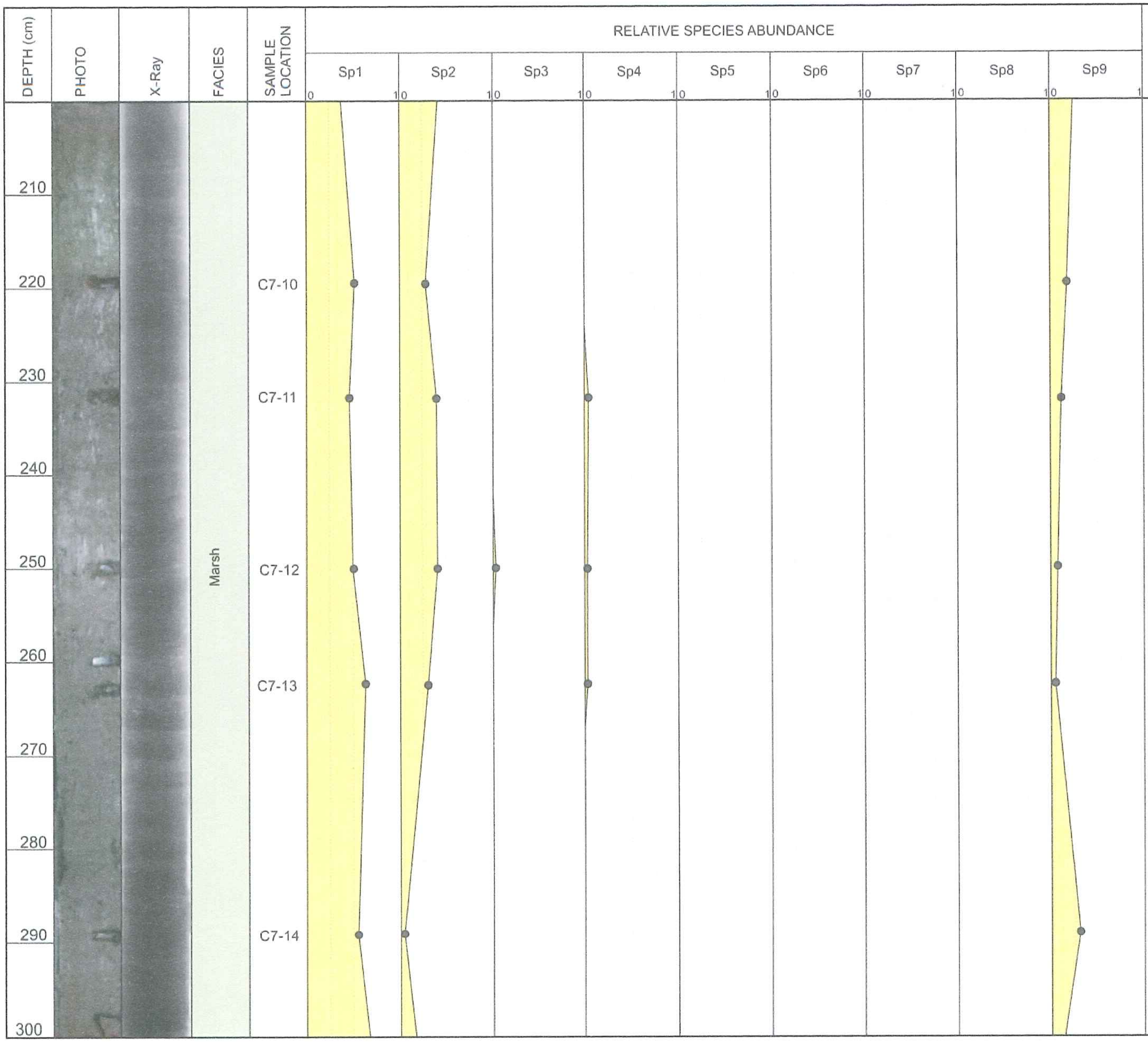
37-78 cm
Grey to light brown colour
Some root structures
Light lense of organics
light grey-yellow modelling

78-117 cm
Grey with brown
Red tint at the base of interval
Black laminations
Black modelling

Core 7-Part 2


DEPTH (cm)
PHOTO
X-Ray
FACIES
SAMPLE LOCATION
RELATIVE SPECIES ABUNDANCE
NOTES
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
10
1
110
120
130
140
150
160
170
180
190
200
Marsh
C7-4
C7-5
C7-6
C7-7
C7-8
C7-9
117-151 cm
Dark brown colour
Root material
Black modelling
Black laminations
Black mostly plant material
151-164 cm
Brown colour
Black organic modelling
Root material
164-229 cm
Light brown colour
Large black organic material
Black modelling

Core 7-Part 3



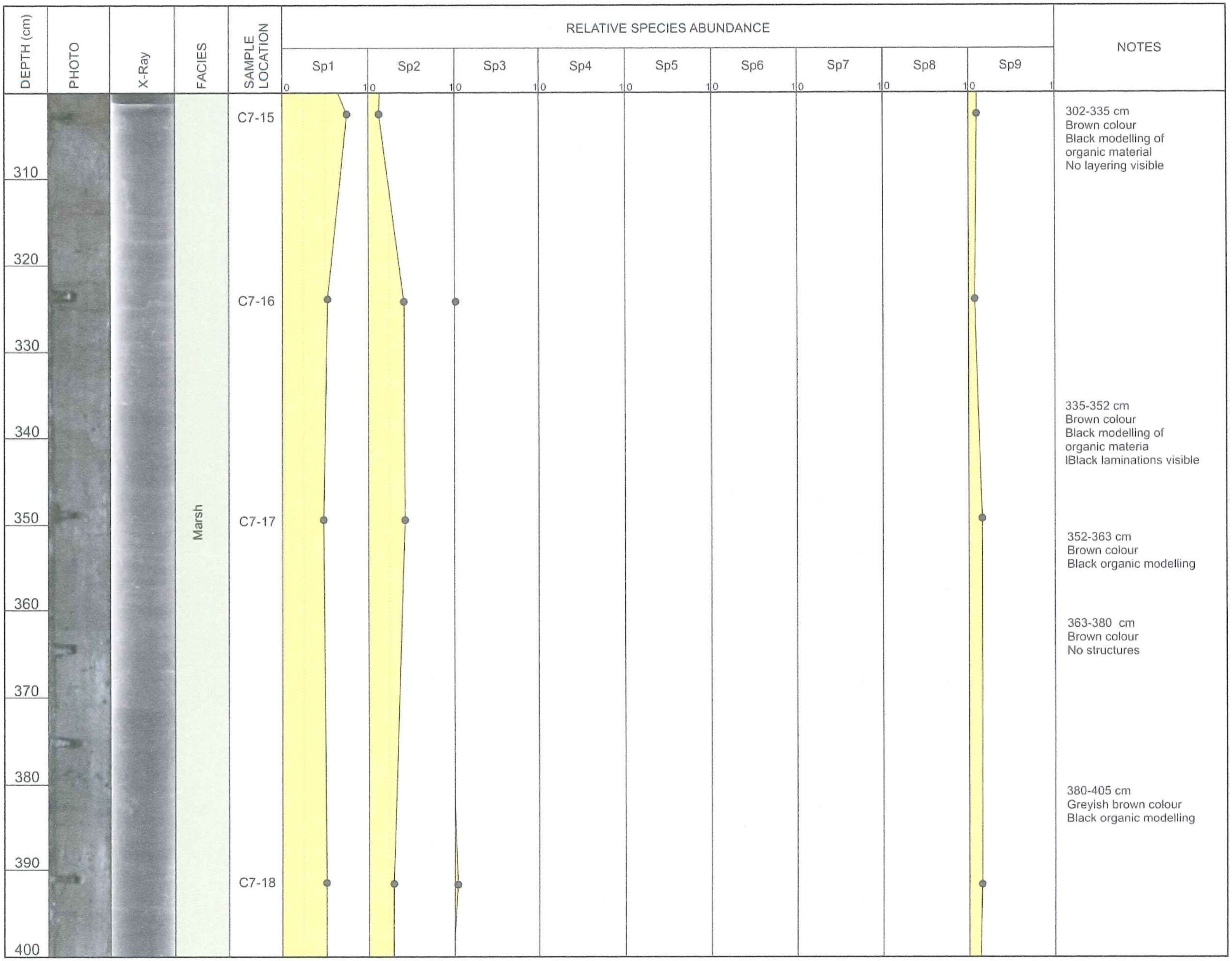
NOTES

164-229 cm
Light brown colour
Large black organic material
Black modelling

229-259 cm
Greyish brown colour
Fine black organics
Black modelling
Some bedding/defined black organic laminations

259-288 cm
Greenish grey colour with gradual change to brownish green colour with increase in depth
Black organics abundant near top of interval, less so near the base

Core 7-Part 4



302-335 cm
Brown colour
Black modelling of
organic material
No layering visible

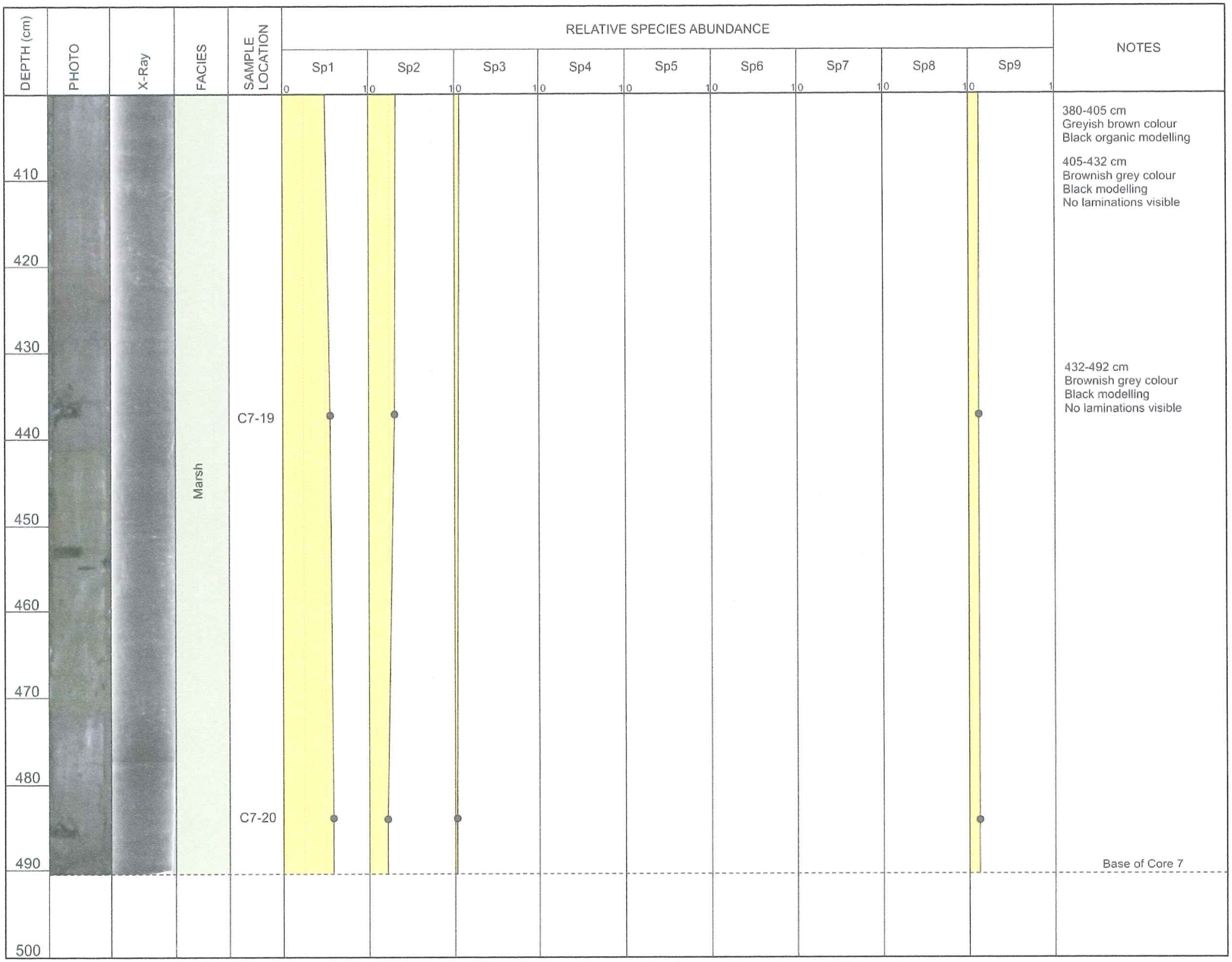
335-352 cm
Brown colour
Black modelling of
organic materia
lBlack laminations visible

352-363 cm
Brown colour
Black organic modelling

363-380 cm
Brown colour
No structures

380-405 cm
Greyish brown colour
Black organic modelling

Core 7-Part 5



380-405 cm
Greyish brown colour
Black organic modelling

405-432 cm
Brownish grey colour
Black modelling
No laminations visible

432-492 cm
Brownish grey colour
Black modelling
No laminations visible

APPENDIX B: Calibration of Radiocarbon Age to Calendar Years

(Variables: C13/C12=-21.6:lab. mult=1)

Laboratory number: **Beta-274231**

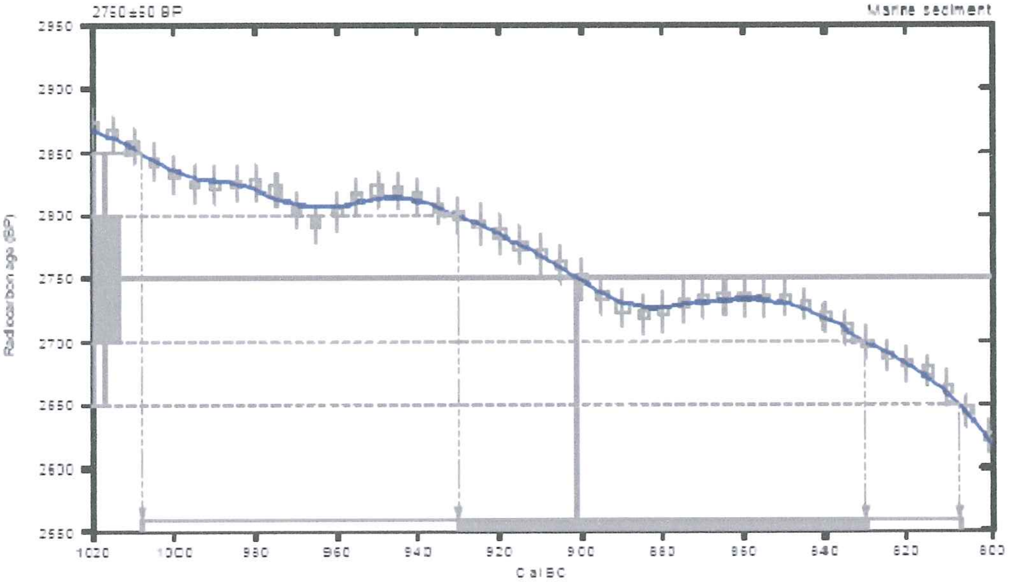
Conventional radiocarbon age: **2750±50 BP**

2 Sigma calibrated result: (95% probability) Cal BC 1010 to 810 (Cal BP 2960 to 2760)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 900 (Cal BP 2850)

1 Sigma calibrated result: (68% probability) Cal BC 930 to 830 (Cal BP 2880 to 2780)



APPENDIX C: Foraminifera Results

Species Reference List:

Sp 1- *Trochammina inflata,*

Sp 2- *Tiphotrocha comprimata*

Sp 3- *Trochammina macrescens f. macrescens*

Sp 4- *Trochammina macrescens f. polystoma*

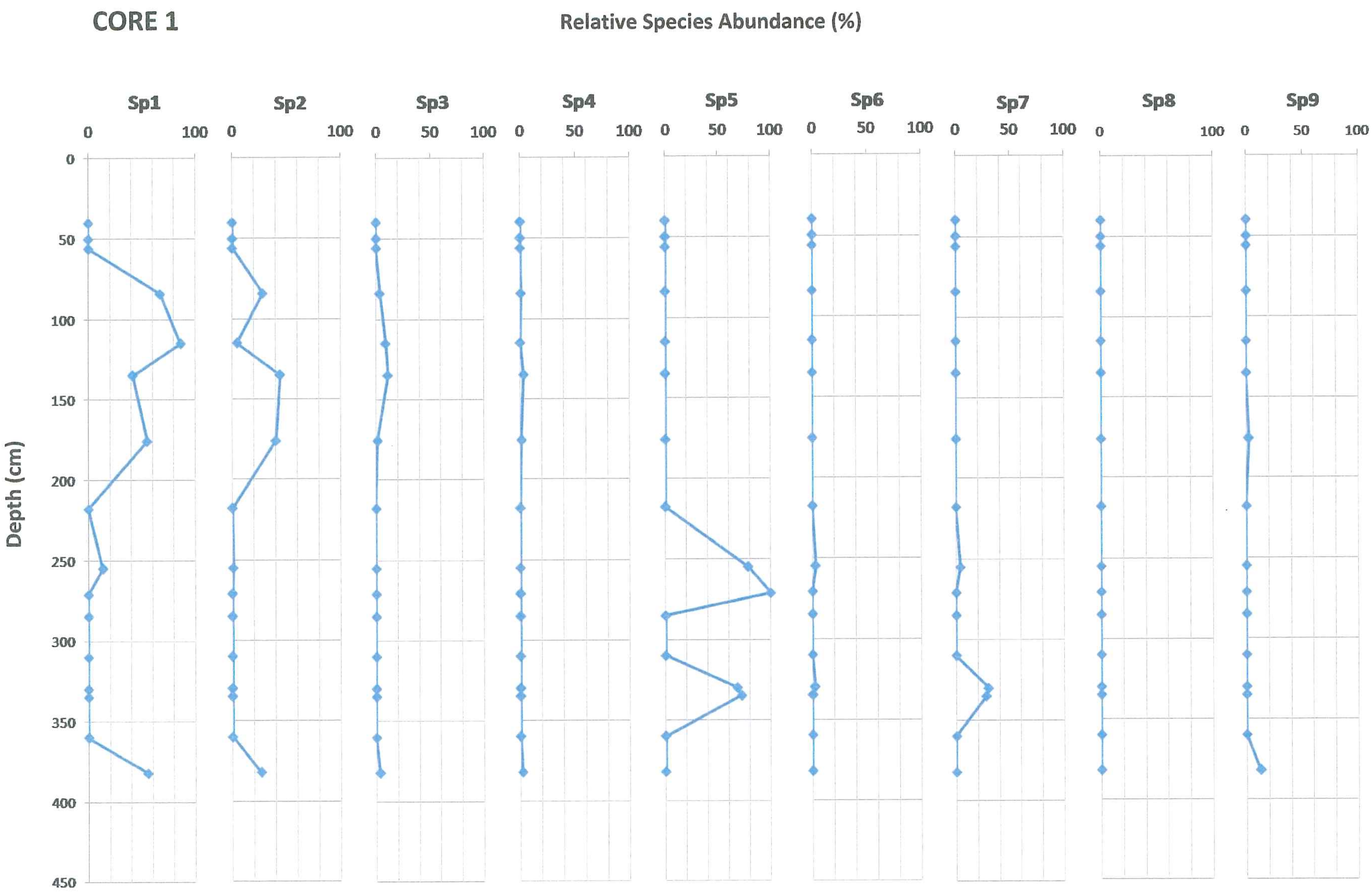
Sp 5- *Pseudothurammina limnetis*

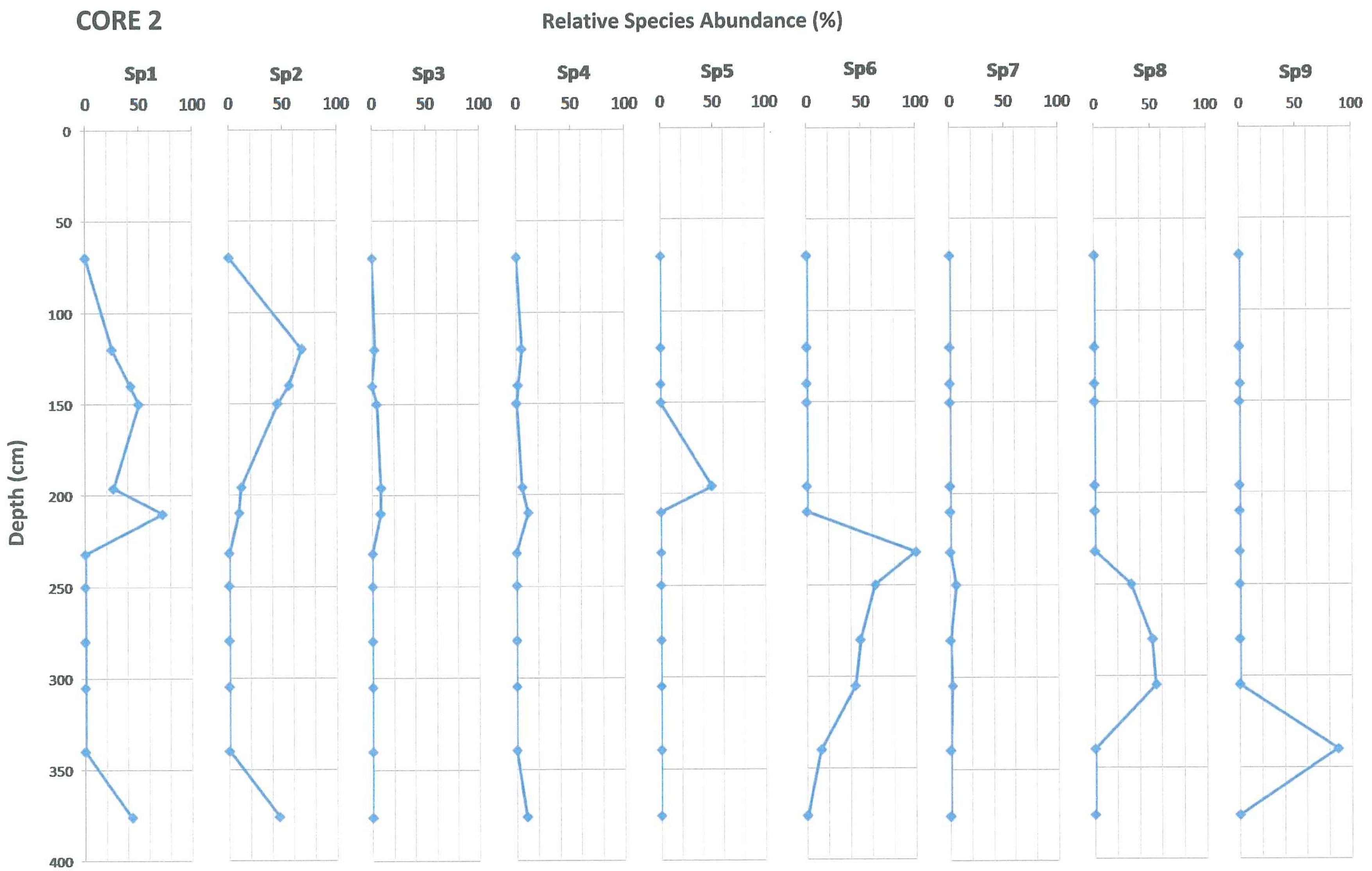
Sp 6- *Elphidium williansoni*

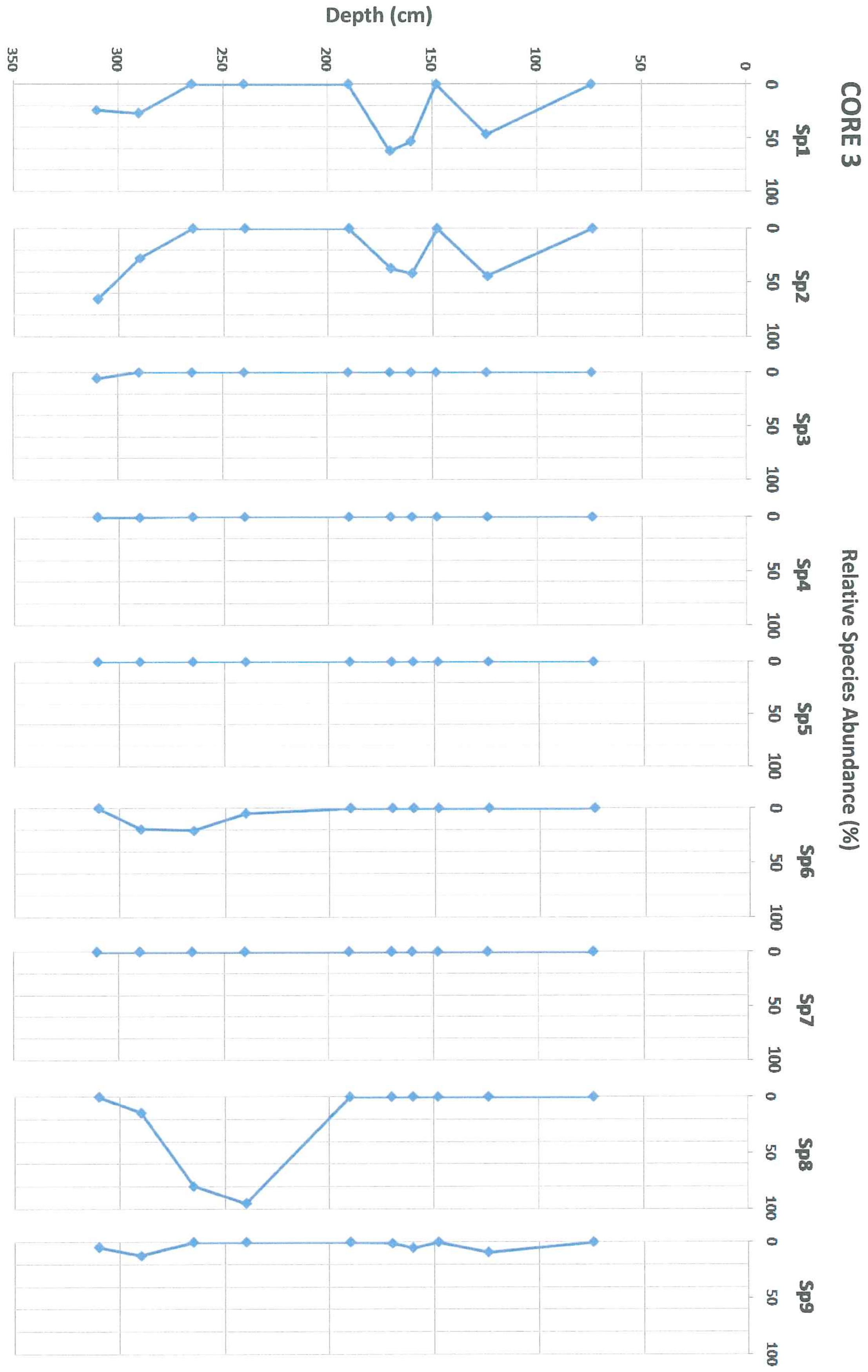
Sp 7- *Elphidium advenum*

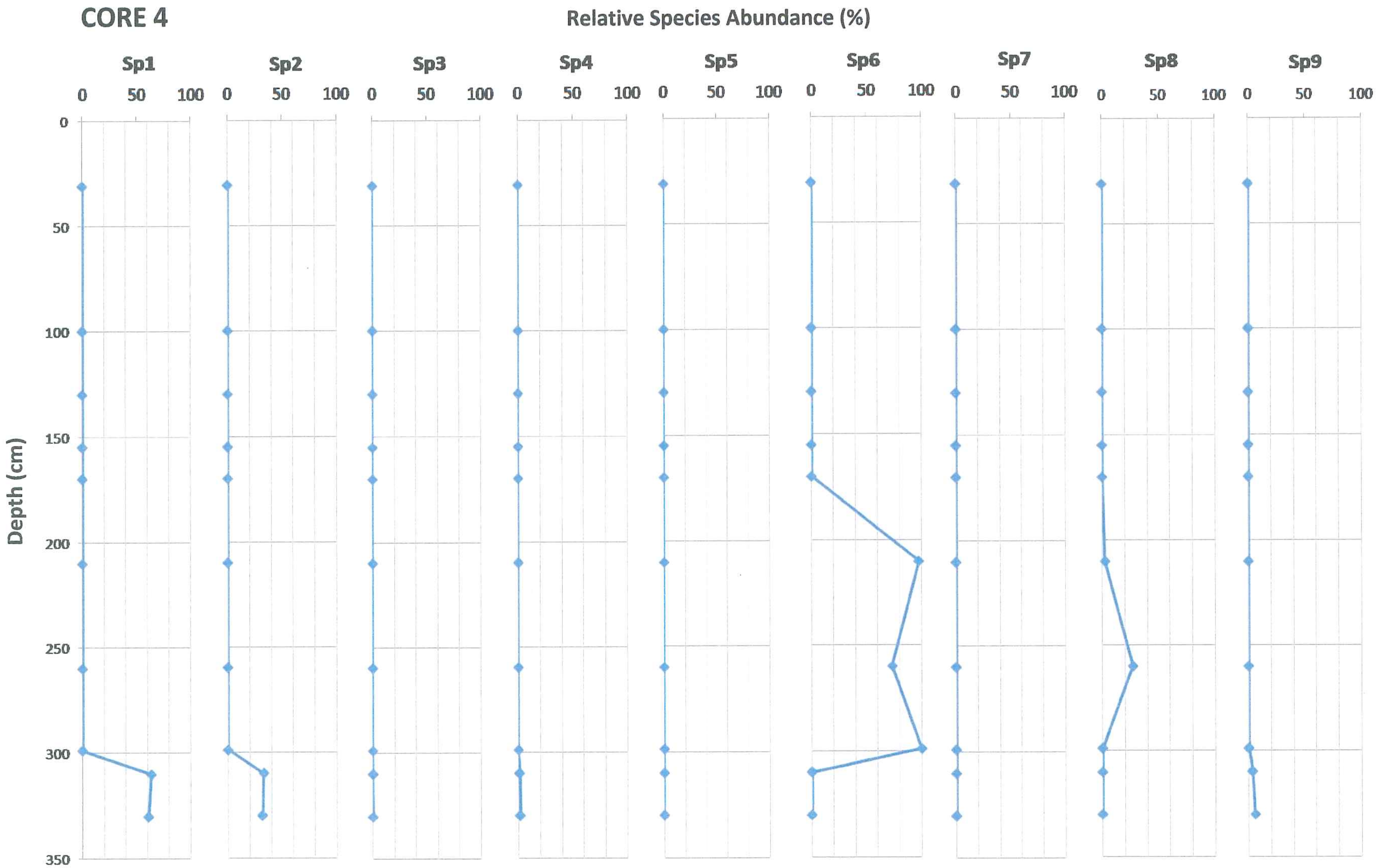
Sp 8- *Haynesina orbiculare*

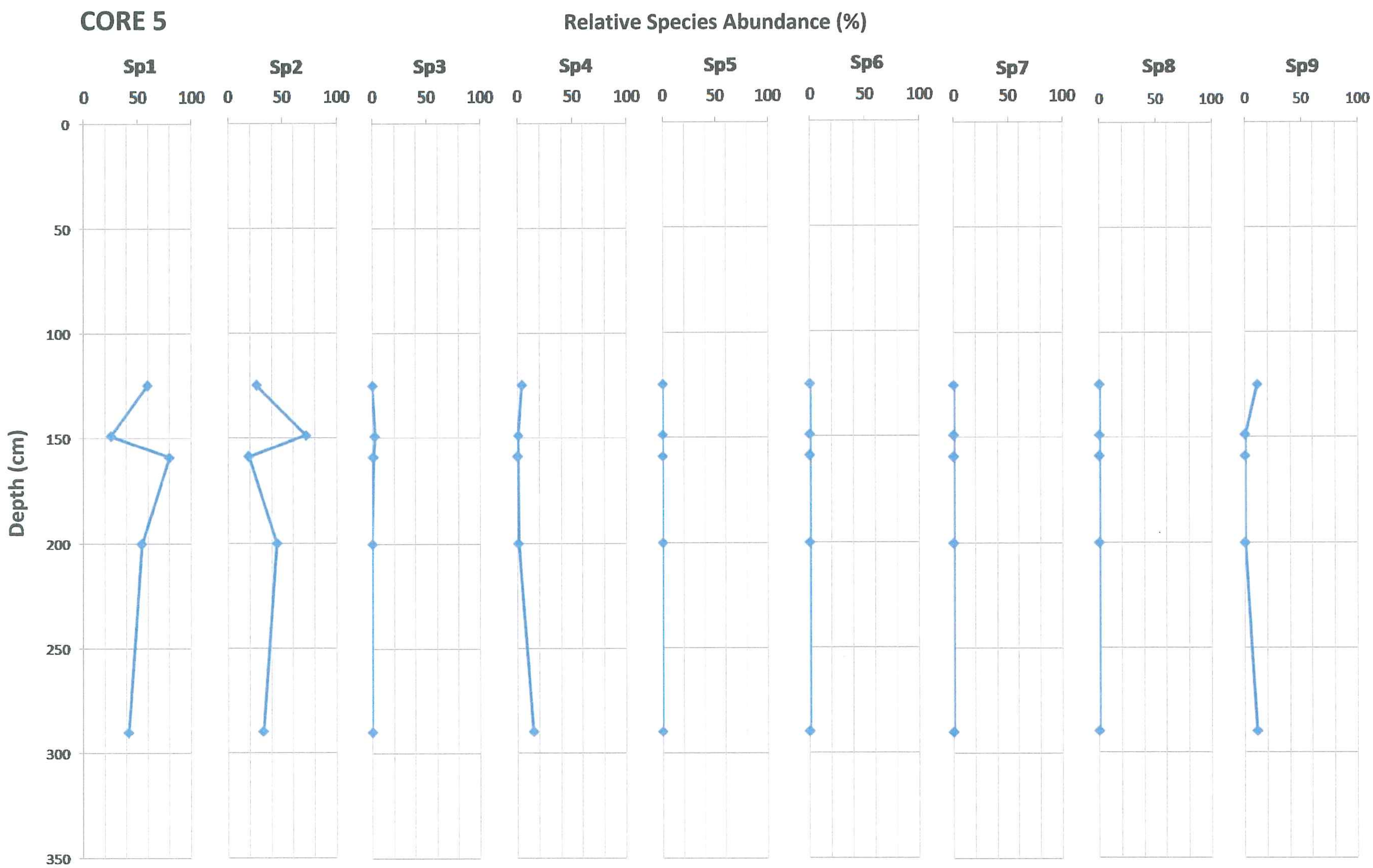
Sp 9- *Arenoparella mexicana*

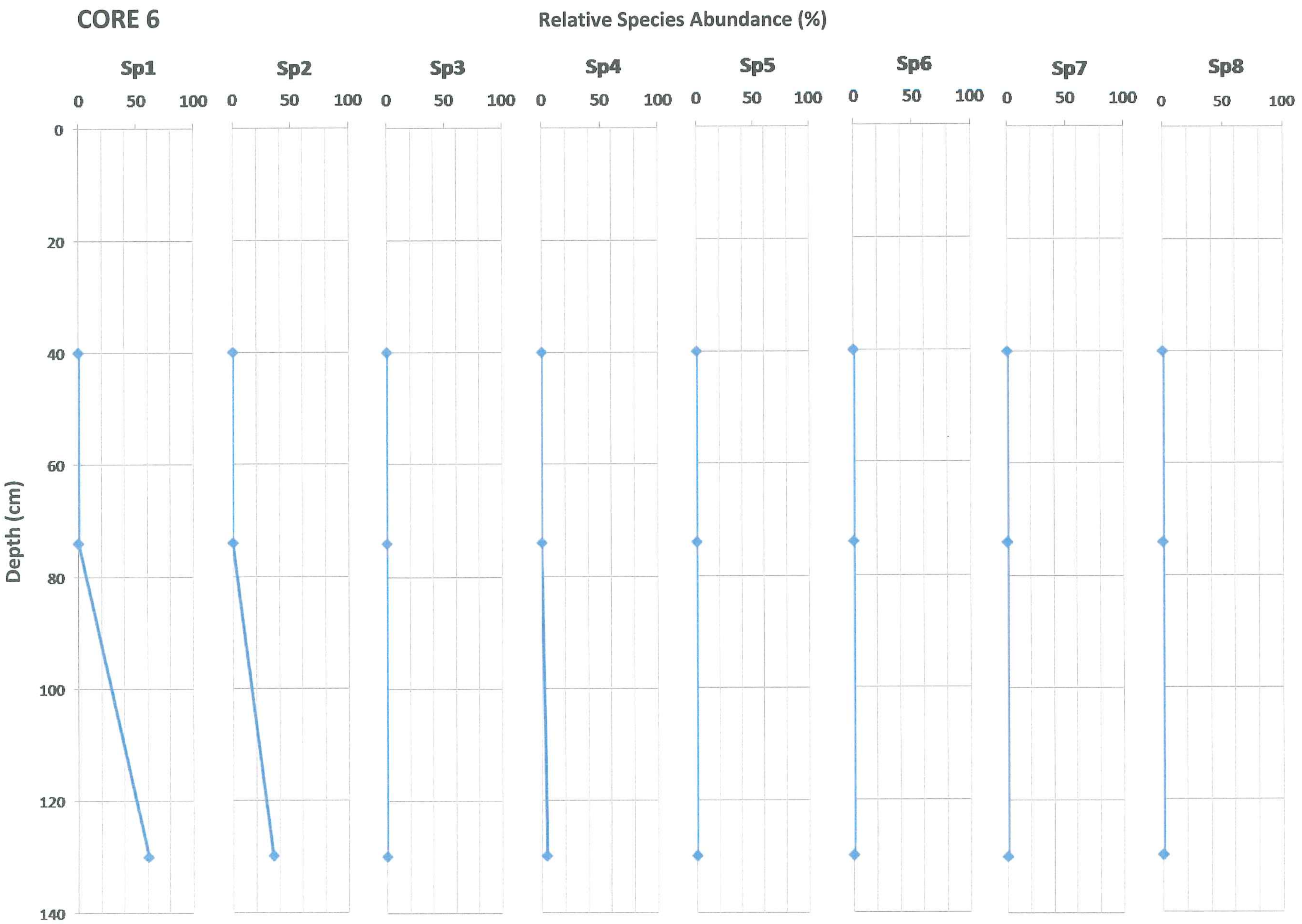

CORE 1
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100
Depth (cm)
0
50
100
150
200
250
300
350
400
450

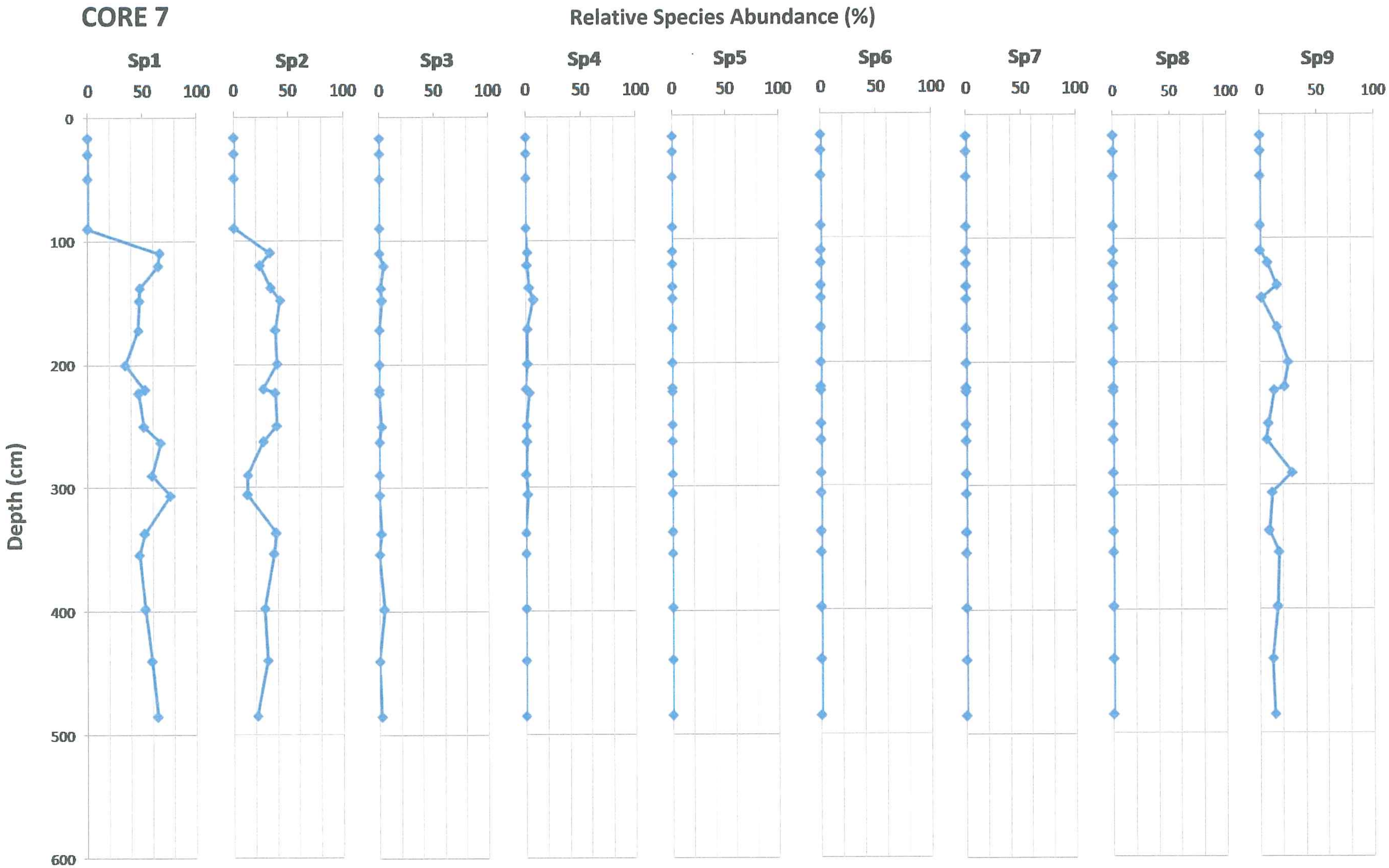

CORE 2
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100
Depth (cm)
0
50
100
150
200
250
300
350
400


CORE 3
Depth (cm)
0
50
100
150
200
250
300
350
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100


CORE 4
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100
Depth (cm)
0
50
100
150
200
250
300
350


CORE 5
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100
Depth (cm)
0
50
100
150
200
250
300
350

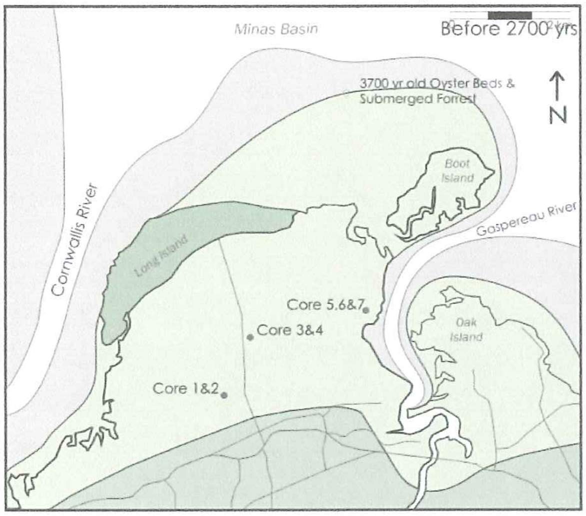

CORE 6
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
0
50
100
Depth (cm)
0
20
40
60
80
100
120
140


CORE 7
Relative Species Abundance (%)
Sp1
Sp2
Sp3
Sp4
Sp5
Sp6
Sp7
Sp8
Sp9
0
50
100
Depth (cm)
0
100
200
300
400
500
600

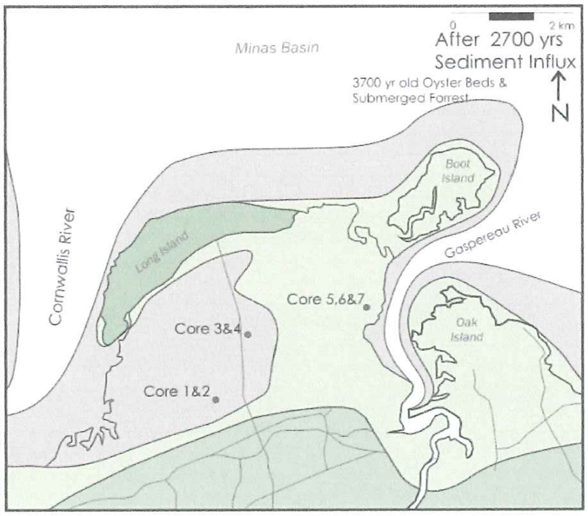
APPENDIX D:

Coastal Evolution at Grand Pré

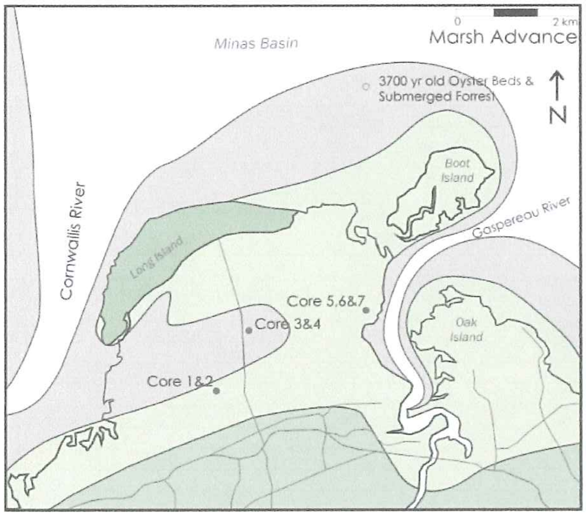
Grand Pre Before 2700 years ago



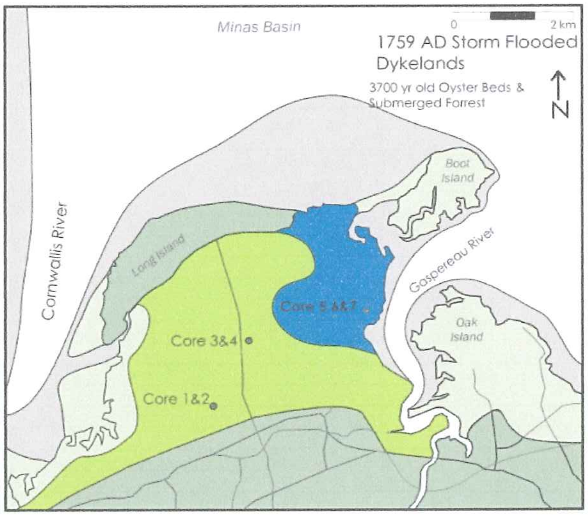
Sediment Influx at Grand Pré



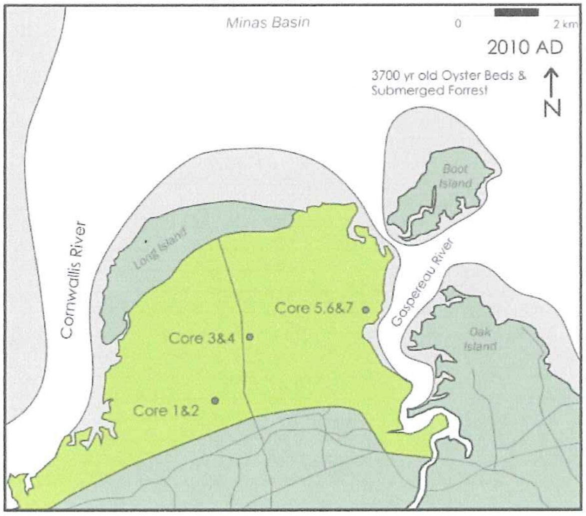
Marsh Advance Development of Tidal Creek System



1760-1761AD Grand Pré



Present Day Grand Pré



Legend

- ⬜ Mudflat
- ⬜ Marsh
- ▨ Mainland
- 🟩 Farmland
- 🟦 Flooded Dykelands