Authigenic Carbonate Mounds and Hydrocarbon Seeps of Offshore Cape Breton Island.

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Abstract

Carbonate mounds that have been dragged up from the seafloor during fishing offshore the Northern Cape Breton Highlands are very distinctive in their nature. The carbonate mounds range in size from a few cm^3 to larger than an m^3 in size. Worldwide, other carbonate mounds have been documented, but they are either much larger or formed in different settings. By studying seismic sections and sampling the hand specimens, the process of their formation can be proposed. Using both Huntec and Airgun seismic data, distinct areas of hydrocarbon mixing with the sediments can be detected. The seismic data also showed a distinct layering between glacial deposits and more recent sediments. Carbon 13 values determined from isotope analysis of shelly debris encased in the mounds showed a distinct negative value in each of the samples. The range for the C13 values is -9.41 to -35.27, with one outlier at -61.38. Considering the isoptopic analysis and the seismic data it seems likely that these carbonate mounds were formed by methanogenesis of hydrocarbon from slow seeps on the seafloor.

Key Words: Hydrocarbon Mixing, Carbonate Mounds, Isotope Analysis, Huntec Seismics, Airgun Seismics, Methanogenesis.

Carbonate Mounds and Seismic Interpretations:
Ryan Cook

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Chapter 1:Introduction

1.1 Introduction:

Off the Northern Coast of Cape Breton Island, under the water near Meat Cove and Cape St. Lawrence are beige carbonate mounds. Harrington (2003) determined these mounds to be composed of carbonate cemented muds, pebbles and bioclastics from a shallow marine environment. The area of study can be seen in Figure 1.1, which is offshore where the Cape Breton Channel meets the St. Lawrence Channel. The questions to be addressed are: how the mounds are formed, is there any relationship to hydrocarbon seeps in the area, and what is the ecological relationship between fish, the fishery and the mounds. The techniques used in this thesis include bedrock and Holocene sediment analysis through seismic data interpretation, hand sample description of other mounds and $\delta^{13}C$ isotope analysis of bioclastic ecology in the mounds.

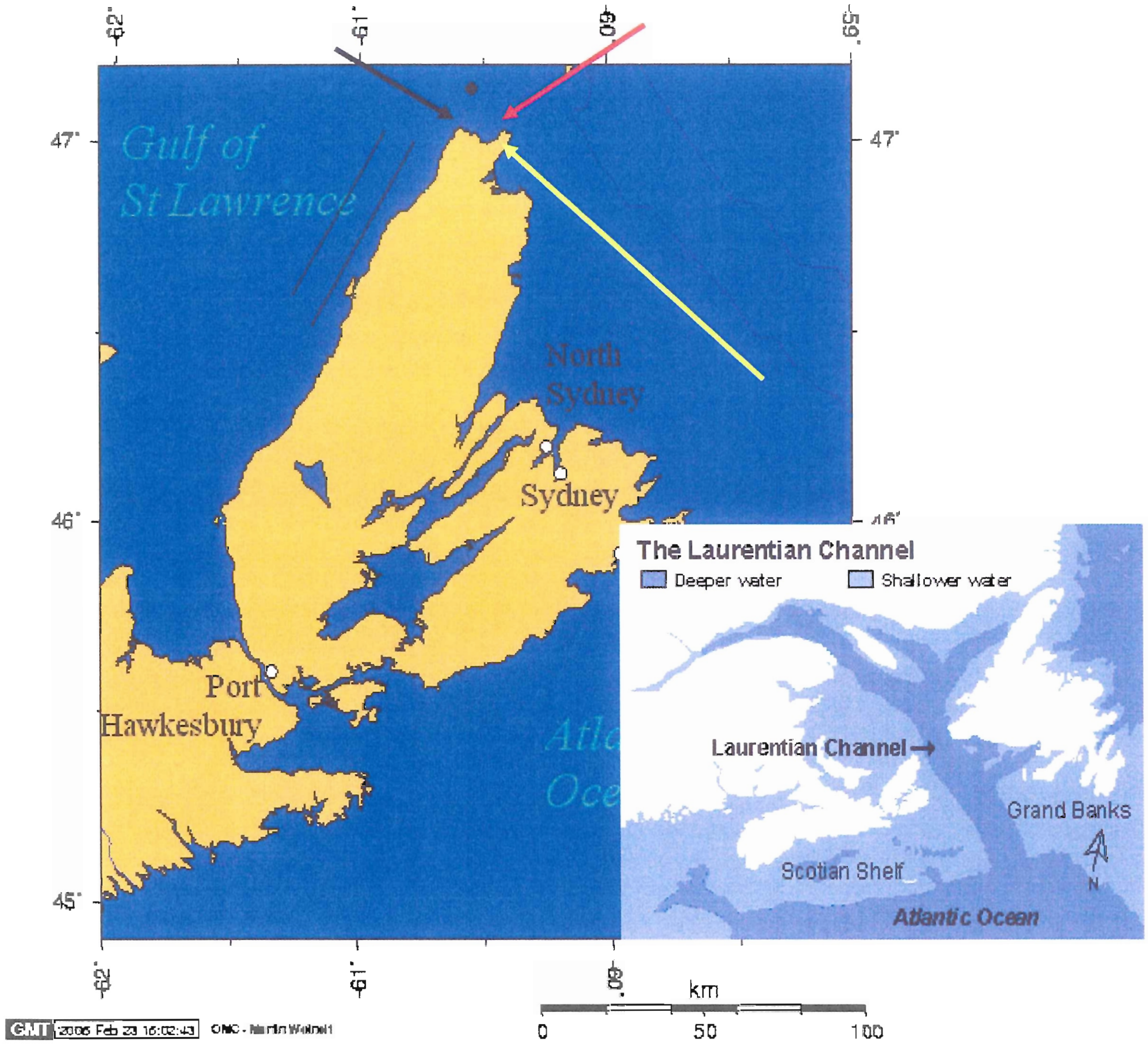

Figure 1.1 Location Map: The parallel lines on the Western edge of Cape Breton mark the Cape Breton Channel; the black arrow shows Cape North. The Black dot indicates the area that the mounds have been found. The red arrow shows the location of Bay St. Lawrence and the yellow arrow shows Cape St. Lawrence. The smaller map shows the whole area of the Laurentian Channel which separates Newfoundland from the rest of Atlantic Canada.

1.2 Purpose:

The purpose of this project is to further our understanding of the carbonate structures found offshore of the Northern Cape Breton Island area.

The goals are:

- To determine whether the mounds are produced by hydrocarbon seeps or trapped methane gas and to develop a model of their formation.
- To generate a better understanding of both the local geology and the relationship of the geology to the occurrence of the mounds.
- To start a dialogue on the importance or relationship of these mounds to the local ecology, specifically the fisheries.

1.3 Location:

The location of the mounds is off the most northwesterly tip of the Cape Breton Island, in an area known as Northeast extension of the Cape Breton Channel off of Cape St. Laurence, seen in Figure 1.1. The carbonate mounds have been found by local dragger fishermen at depths of some 160-210m, approximately 5km out to sea. It was not possible to retrieve fresh samples from their in-situ location, instead the samples were taken from a local fishermen's wall, seen in Figure 1.2. The Carbonate mounds are found on the surface of the sea floor or up to a depth of a meter or so (i.e. depth of drag nets), and are frequently dredged up by local fisherman while they fish for sole although some of the samples brought to the surface show signs of other fishing practices on them. The number of samples brought up each year by an individual fisherman is around 24 a year on average.

Figure 1.2: Shows a Carbonate Mound Wall around a fisherman's house. Samples from this wall were used in this study. Photo by Peter Wallace.

1.4 Organization:

The organization of this thesis has Chapter 1 as the introduction, which includes purpose, location, organization and the methods used. Methods has 5 subsections which are geological assessment, hand sample analysis, isotopic analysis and ecology and effect on the fisheries, and seismic data interpretation. Chapter 2 is the background section of the project and is broken up in to 6 sections: introduction, regional bedrock geology, recent sediments, carbonate mounds, and the carbon isotope. Chapter 3 consists of: Introduction, sample description, isotope sample data, and seismic interpretation. Chapter 4 presents a model of mound formation and then covers a discussion of the significance of seismic and isotope data as a source of hydrocarbons. Chapter 5 will present the conclusions of this study.

1.5 Methods Used:

Methods used include geologic assessment and hand sample analysis, ecology and the effect on the fisheries, isotope analysis, and seismic data interpretation:

1.5.1 Geological Assessment:

The Geology of onshore and offshore of the Northern tip of Cape Breton Island is difficult to find on maps because very little work has been performed on the area. The purpose of this study is to compile an understanding of the bedrock and Holocene geology from prior work to see if there is a link between geology and the mounds which will help in understanding or developing the model of mound formation.

1.5.2 Hand Sample Analysis:

The initial step is to view the samples to establish what they are and compare them with the initial ideas of Harrington (2003). Are these structures related to organisms or do they have more to do with environmental controls? Harrington (2003) only had access to 6 mound samples and therefore his description of the mounds was only the first step in their analysis. In the subsequent years we had access to more samples from the wall shown in Figure 1.2, plus one fresh sample brought to the university by a fisherman during the fall fishing season (2004).

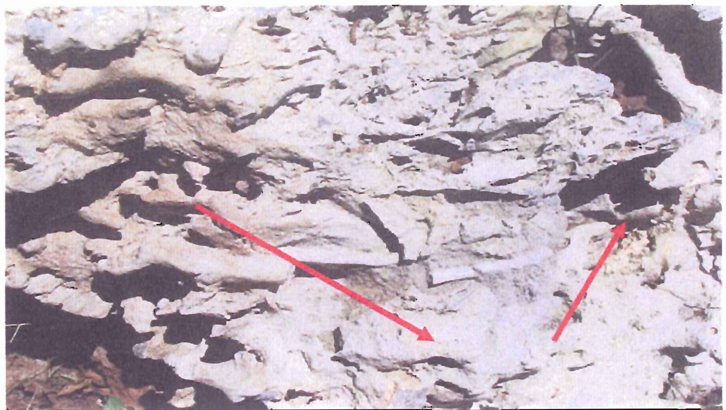

Figure 1.3: Carbonate Mound, with possible tube worm burrows. Provided by Peter Wallace

1.5.3 Ecology and effect on the Fisheries:

This area is particularly important to the local fishery because in their opinion it seems to be the only location in Eastern Canada where Sole can be fished. Why Sole have a particular affinity to these mound-like structures is unknown. Also unknown is whether or not the activities of the fishermen of the area are effecting this habitat.

1.5.4 Isotopic Analysis:

The carbonate mounds underwent an isotopic analysis to determine the amount of $\delta^{13}C$ present in the sample. This will show whether or not the ^{13}C source is from recent sediments or from the bedrock. The lab performing the analysis is located at St. Francis Xavier University and is called the Isotope Ratio Mass Spectrometer (IRMS) lab. The lab used a process known as combustion which burns oxygen to determine the $\delta^{13}C$ values of the samples.

^{13}C is heavier than ^{12}C so organic processes (i.e. respiration, etc.) it will concentrate ^{13}C in tissue and the carbonate shell (adds ^{12}C). This leads to a negative trend of ^{13}C. Upward hydrocarbon migration coupled with bacterial methanogenesis will enhance this. Therefore if you can compare ^{13}C values in organisms a negative trend indicates ancient or methanogenetic carbon. The data that is produced can then be used to understand the mounds, and allow for an understanding of the source of ^{13}C. To prepare a sample for isotopic measurement, the samples are cleaned which includes dremmeling off a thin surface layer. This is to remove any contaminants that have occurred recently and to give a fresh surface from which to retrieve the sample.

1.5.5 Seismic Data Interpretation:

Three lines in the vicinity were looked at for evidence of hydrocarbons in the signal and markers to use in interpreting the bedrock and recent (Holocene) geology. The first step in analyzing seismic sections is to compile the section and separate the stratigraphic units. The next step is to indicate sections that appear to have been disturbed by unknown events (possible out gassing from the sediments in this case). The key items looked for included hydrocarbon indicators such as columnar disturbance, turbidity, bright spots, diapir, and the contacts between Holocene sediments, glacial debris and bedrock. The seismic sections themselves were produced using an Airgun seismic device, which sends out a signal from a gun towed behind a boat. The signal is directed down at the seafloor, and then returns to the surface. Or the Huntec high resolution seismic which works at a higher frequency then the Airgun seismic device.

Chapter 2: Background

2.1 Introduction:

The carbonate mound structures that make up the basis of this project are located under the water approximately 5km offshore northern Cape Breton Island. The samples retrieved from depth range in size from a couple of cm wide to >1m. Their occurrence is potentially related to hydrocarbon seeps associated with either modern (Holocene) methane in the sediments or from older source rocks that lay along major faults. The older rocks are possibly of the Carboniferous age. The interpretation of Huntec as well as Airgun seismic data will show the near surface geology as well signatures indicative of gas-laden sediments. Determining the regional geology will help with the interpretation of the seismic sections. $\delta^{13}C$ (Carbon) isotope analysis will be used to help determine whether or not the carbon in the carbonate mounds are of recent origin or have underwent a process involving an older source.

2.2 Regional Bedrock Geology:

There has been very little work done on the geology of the area, or on these or similar sized carbonate mounds.

The previous geological work that has been done on the offshore Cape Breton area focused on bedrock geology and recent sediments to the Northwest and Southeast but not specifically this area. The bedrock geology was compiled from a number of sources, which includes the modified version of the geology of Cape Breton Island seen in Figure 2.1. Figure 2.1 has several different groups of rocks but the two of importance to this study are indicated by the arrows. The red arrow indicates the Horton Group rocks that consist of sandstone, conglomerate and shale, and the yellow arrow points to the Windsor Group rocks that are made up of limestone, siltstone, gypsum and anhydrite. The other rocks on the mainland are a mix of gneiss, amphiboles, schist, marbles in the burgundy section and intrusive syenite in the dull orange colour on the map.

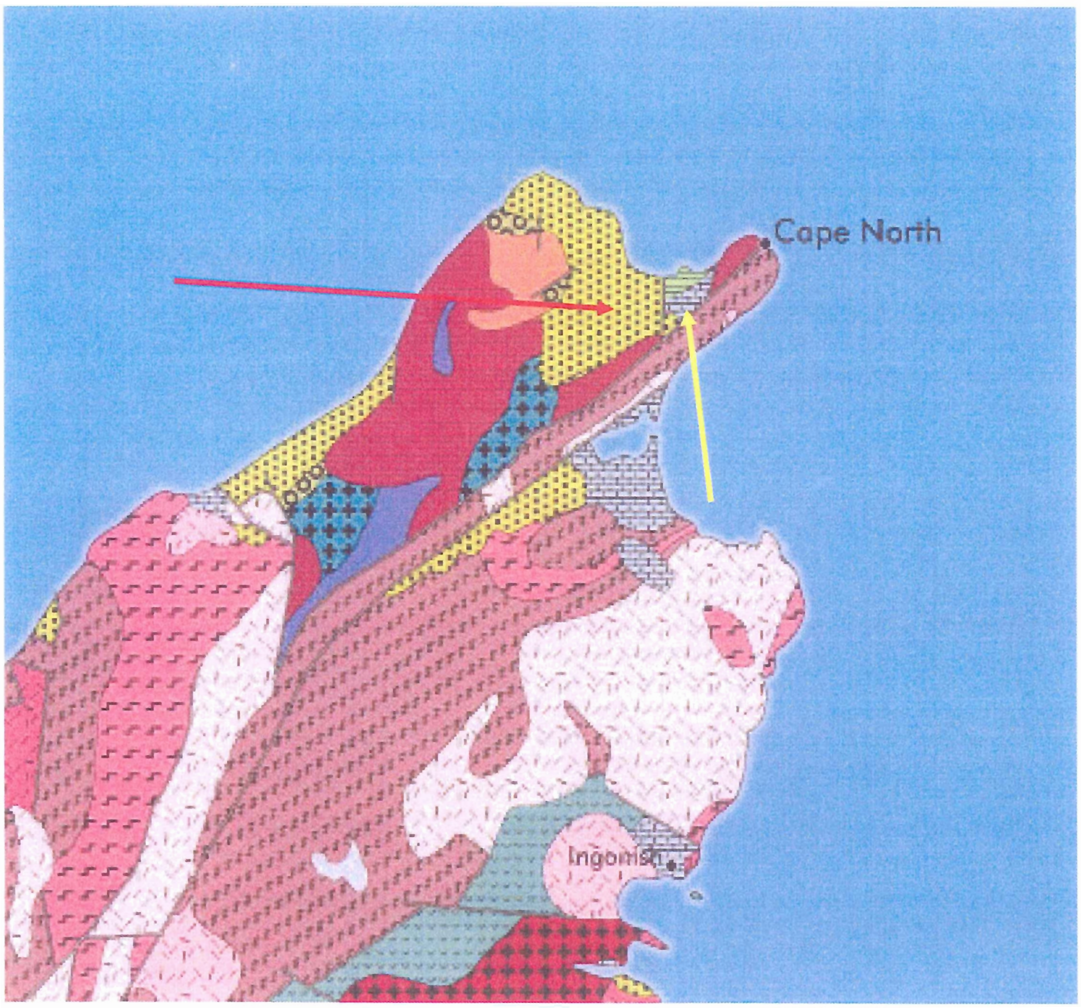

Figure 2.1: Geological map of the Cape Breton Highlands CBI. Red arrow points to Horton Group rocks and the yellow arrow to Windsor Group rocks. These are the rocks that are important to this study. From Gray (2000).

The Horton Group are the source rocks for the potential hydrocarbon seeps. The Windsor Group is the reservoir rock for the hydrocarbons. The on-land distribution in the immediate area of both is mainly the Horton Group from Cape St. Laurence to Bay St. Laurence in the North, and the Windsor Group is East in Bay St. Laurence. However Figure 2.2 shows salt structures north to Northwest of Cape St. Laurence which is also Windsor Group. The contacts between the Horton Group and Windsor Group are mainly faults but the Horton is Older than the Windsor. Although the current idea of on-shore geology seems fairly straight forward, the same can not be said for the off-shore. With several major fault zones in the area the offshore of Cape Breton Island can be fairly complicated. Lastly 'oil' seeps have been described onshore which has been interpreted as rocks related to the Horton and Windsor Groups. This shows onshore association of hydrocarbon rocks with the Horton and Windsor Group. So the seeps that are related to the carbonate mounds may also be associated with the Horton and Windsor Group rocks. This can be seen in Figure 2.2.

Figure 2.2: The oil shales (indicated by the yellow arrows) along Cape Breton Island's coast line. These are the likely source for the offshore hydrocarbon supply to the carbonate mounds (Picture courtesy of Peter Wallace).

The offshore area is covered in a myriad of faults, the major ones that affect the bedrock of the area are the Hollow Fault Zone (HFZ), Wilkie Brook Fault and the Aspy Fault. The Aspy Fault does not play as significant a role as the other two due to its location being further away from where the mounds are actually found. The HFZ has the most direct affect as it runs almost on top of the carbonate mound location. The HFZ is a dextral transverse fault, this fault will allow any potential trapped hydrocarbons in the bedrock to be freed and have routes to the recent sediments and surface. Although there appears in Figure 2.3 that there is a break in the HFZ where it becomes offset from its previous line, this could be related to the presence of possible salt domes in the area. Langdon and Hall (1994) studied the salt structures in the Cabot Strait with attention paid to both Bay St. George and Hollow Fault Zone. In that paper they suggest that the Horton Group can be seen near St. Paul Island, which is near to the location that the carbonate mound samples were brought to the surface. Also the paper suggests that in this area above the Horton Group rocks, which are in the bottom of a graben, there is distinct evidence of salt flowage in seismic sections (Langdon and Hall, 1994). These salt structures/domes are useful in both breaking a path for hydrocarbons to reach the ocean floor due to salt's natural affinity to move to an area where the salt's density is equivalent to the surrounding rocks and salt domes are renowned to trap hydrocarbons along their flanks.

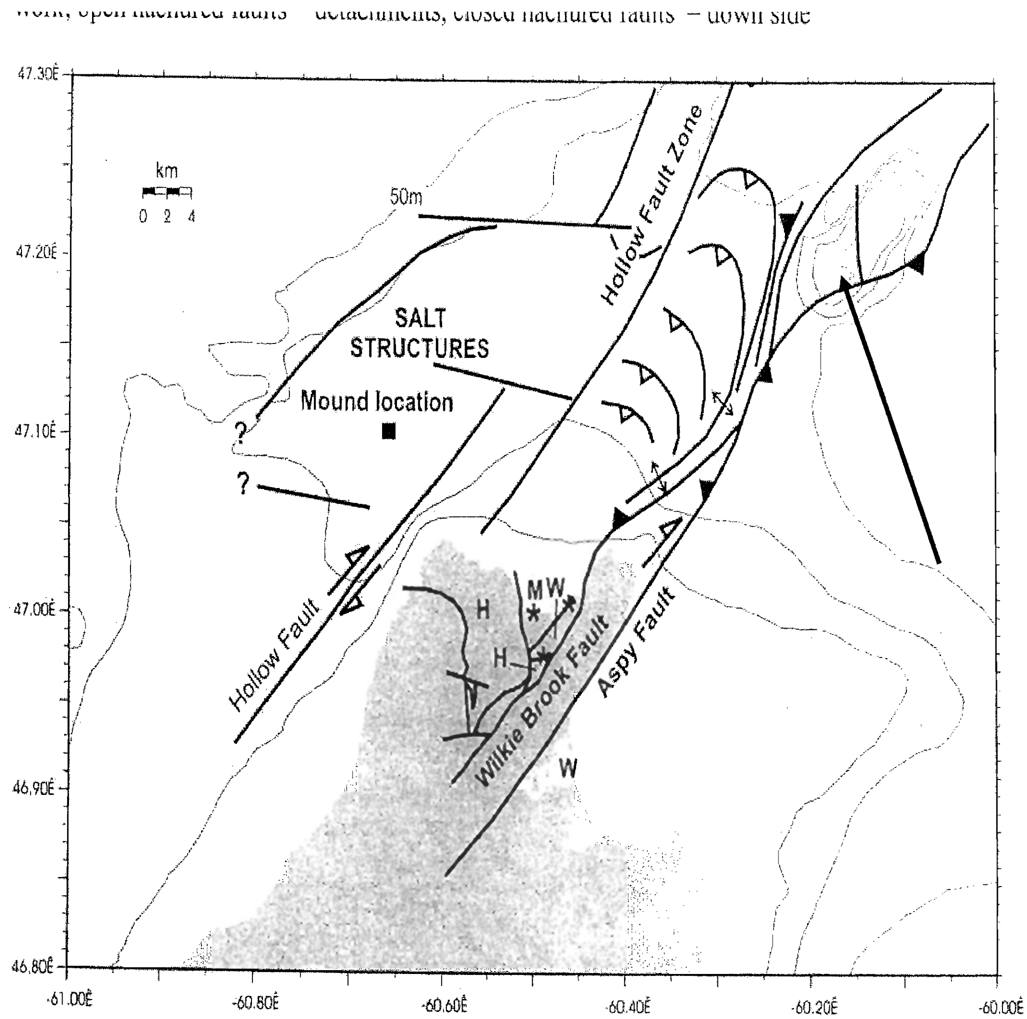

Figure 2.3: The network of faults in the study area as well as the locations of possible salt structures that may have an affect on hydrocarbon supply for the mounds. Major Faults in the area are Hollow Fault Zone, Wilkie Brook and Aspy Fault. The black arrow indicates St. Paul Island. (Wallace, 2006)

2.3 Recent Sediments:

The recent unconsolidated sediment can be attributed to two times of deposition, the first being till from the last major glaciation and the next being recent sedimentation after the Gulf of St. Lawrence became ice free. The glacially distributed sediments have very little structure to them, and are mainly massive clays that contain rock debris of varying sizes (Josenhans, 1999).

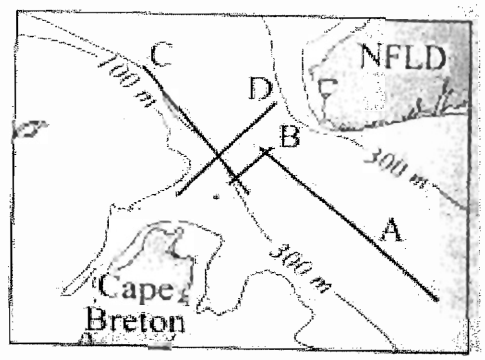

Figure 2.4: Location of Seismic line data. From Josenhans, 1999

The glacial till conformed to the sea floor when deposited, meaning that any valleys or depressions will fill with till and be smoothed out (Josenhans, 1999). The more recent

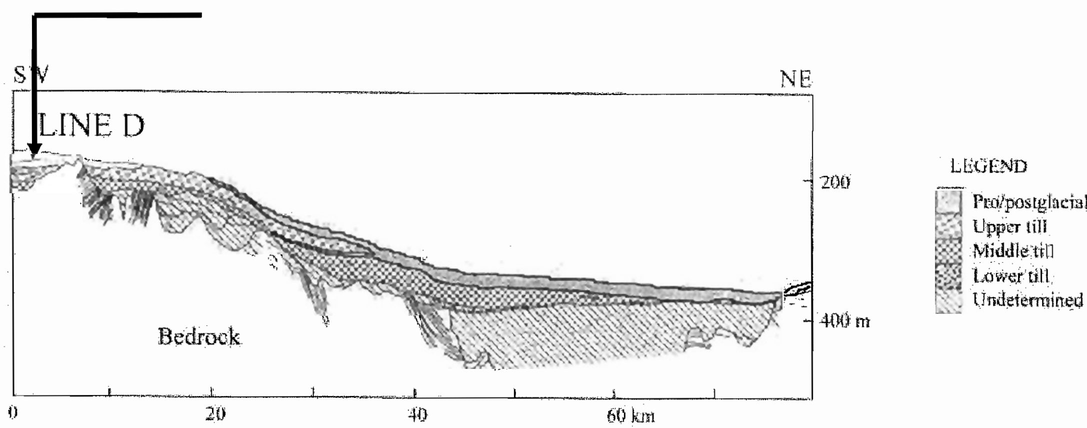

Figure 2.5: Cross section of offshore Cape Breton Island and part of the Laurentian Channel along line D of Figure 2.4. This data retrieved from a section slightly further offshore than where the mounds were retrieved. Modified from Josenhans 1999.

sediments are mostly mud and silt and have a very planar bedded nature. Figure 2.4 shows the area in which the seismic lines were taken including Line D which Josenhans (1999) uses to determine the seafloor geology in Figure 2.5. Also in that paper Josenhans

(1999) describes the results of the last glacial period on the Laurentian channel plus the recent marine sediments, from seismic data. Josenhans (1999) mentions pock marks, but not mounds specifically, and avoids the issue of hydrocarbons in the sediment.

The recent sediments are distributed throughout the Laurentian Channel and the Cape Breton Channel, which is shown in Figure 2.4 by the out lined section and Figure 2.5 (Josenhans, 1999). The sediments in the study area include pro/post glacial, Holocene muds, glaciomarine material and tills (Josenhans, 1999), all of which occur in some volume in this study area.

2.4 Carbonate Mounds:

Very little is known about the carbonate mounds found off-shore Cape Breton Island. Harrington (2003) is the only person to have previously described the mounds. Harrington only had access to 6 samples while he did his research, while many more were available for the purposes of this one. Harrington determined that there are three types of mounds in those 6. The first is called 'popcorn' structure, which has little to no layering and minimal erosion. Popcorn type carbonate mounds also have on occasion dendritic branches (8-10mm) and their interiors are finer grained clasts than their exteriors. The second type is called layered, and is defined by the grain size and/or the overall textures/structures. The layered mound samples are generally dominated by fine-grained siliciclastic material and have smooth and rounded edges and exteriors. The layered mounds have a high carbonate content (95%). The third type of carbonate mound is the eroded type. Eroded mounds are highly porous and have very little of their original texture. The erosion is from both biological and chemical erosion. This type of mound is the least common of the three types that Harrington (2003) described.

Carbonate mounds from other locations have been described in greater detail. These locations include the Caribbean, off the coast of British Colombia and in the North Sea. The mounds from the Caribbean and the North Sea are of a size that dwarfs those of Cape Breton Island. Compared to the slightly over a 30cm examples dredged from the seafloor off Cape Breton Island the other mounds are 10s to 100s of meters in size. Although the samples examined for this thesis are possibly only broken specimens of a much larger body, it is unlikely that they are much larger given the way they are dredged from the seafloor. The mounds off the British Columbian coastline are similar in size to those from Cape Breton Island according to locals; however they are formed at deeper depths.

2.5 Carbon Isotopes:

The method of analysis for carbon isotopes involves "burning" of the sample in atmospheric O_2 and the resultant CO_2 is analysed for isotopic ratios. The O_2 data becomes contaminated during the process, making the data unusable.

Using the bioclasts contained in and on the mounds, $\delta^{13}C$ values can be determined. A good source for values of $\delta^{13}C$ is invertebrate sessile benthic creatures and the authogenic sparry calcite cement and coatings. There is some concern with the values measured due to biological fractionation (Carpenter 1995) that occurs during a metabolic process that brachiopod shells undergo. This happens more severely in the primary layer of calcite, which includes parts of the brachiopods hinge and muscles scars (Carpenter 1995). The primary layer tends to have values of $\delta^{13}C$ that diverge from the values that are produced when analysing the secondary layer. Carpenter (1995) suggests that this could be due to the degree of fractionation in the primary layer or the isotopes of carbon had varying composition. However Carpenter goes on to say that the results could be in error due to the thinness of the primary layer, and the procedure used to extract material from that layer could have collected values from the secondary layer as well. This difficulty is overcome by taking samples from a specific area of a Brachiopod shell that is only a primary layer like the hinge and doing the analysis on that (Carpenter 1995). However this option was not always available when sampling the shells for this thesis, due to the nature of the way the shells were embedding in the mounds. Carpenter (1995) produced several $\delta^{13}C$ vs. $\delta^{18}O$ graphs, one of which is from recent brachiopods in the Bay of Fundy (Figure 2.6), and is reproduced here because of its proximity to Bay St. Lawrence and because it has no known hydrocarbon

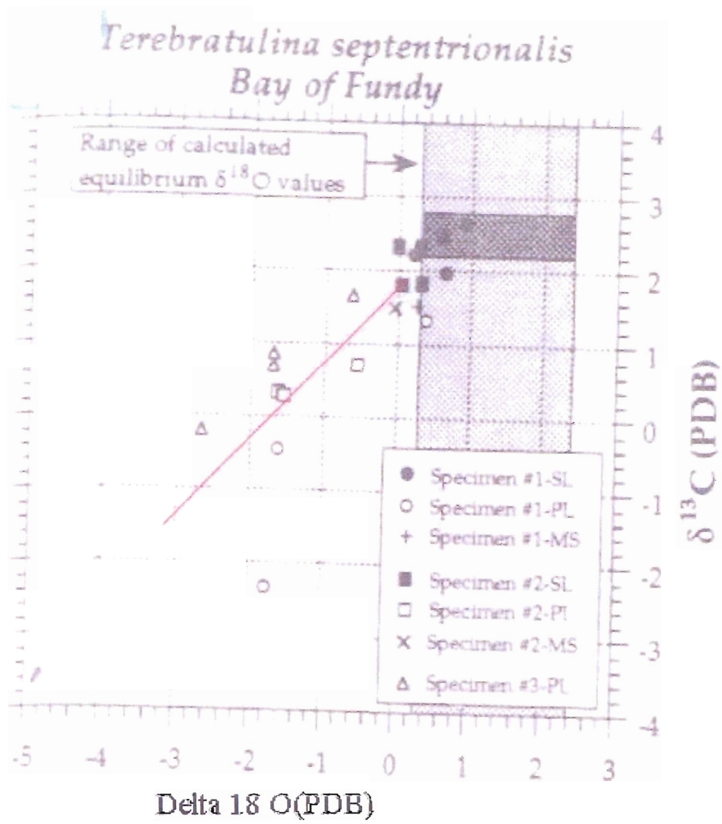

Figure 2.6: ^{13}C vs. ^{18}O isotope concentrations for brachiopods in the Bay of Fundy, the red line indicates the linear trend. Figure from (Carpenter 1995).

influences. The $\delta^{13}C$ values obtained range from +2.0 to -2.2, with most occurring on the positive side of 0.

Hughes (1988) uncovered another possible reason for fractionation of the primary layer. While studying *Terebratalia Transversa*, results showed that the anterior portions of the Brachiopod shell produced almost 4 times the amount of metabolic activity than that of the posterior portion. The anterior portion of the Brachiopod is responsible for producing the primary layer, while the posterior produces the secondary layer (Carpenter 1995). This results in a larger fractionation for both the carbon values and the oxygen values in the primary layer as opposed to those seen in the secondary layer. However this is difficult to correct for due to the way the shells were embedded.

Roberts (1998) determined in his paper the values of $\delta^{13}C$ for both normal marine and seep related carbonates. In the paper there is segregation between the two types which will be helpful for the purpose of this thesis. The range of the normal marine values produced in Robert's paper ranged from +2 to -6 ‰PDB for $\delta^{13}C$ compared to the seep-related carbonates which have a wider range in values and are more negative (-18 to -54 ‰PDB) (Figure 2.7).

By comparing the data determined during this thesis with these two sets, it is possible to determine the origin of the hydrocarbon.

Most of the samples used for analysis were clams (pelecypods), which will have some bearing on the $\delta^{13}C$ results. The shells of pelecypods are aragonite, which is metastable. After the organism dies the shell begins to turn in to calcite. This is not true for the brachiopods which make their shells out of calcite to begin with.

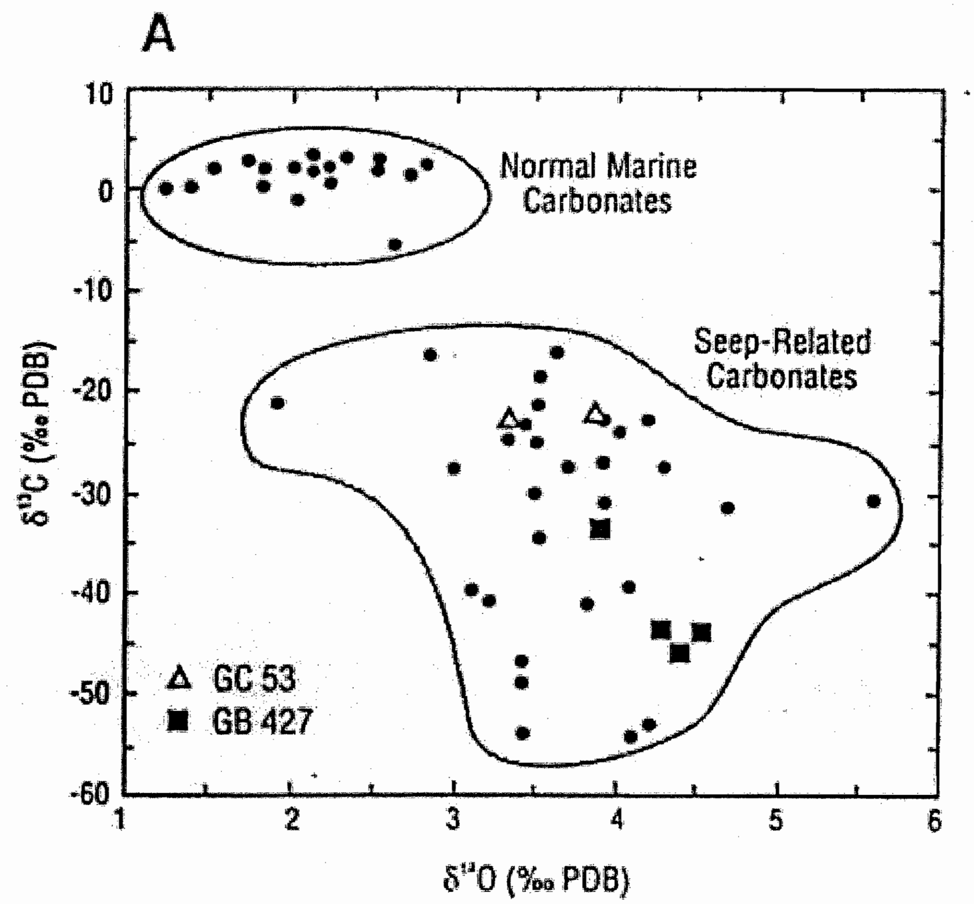

Figure 2.7: $\delta^{13}C$ vs $\delta^{14}O$ graph showing the values of carbonates relating to their sources from Roberts (1998).

Chapter 3: Results

3.1 Introduction:

The carbonate mounds that fishermen of the Cape Breton Highlands region dredge up from depths of 160-210m from the ocean floor provide the basis for the study. The results produced from those carbonate mounds will be detailed in this chapter in the following categories.

1. Mound Description and Ecology
2. Isotope Sample Data
3. Seismic Interpretation

3.2 Mound Description and Ecology:

The sample carbonate mounds brought to the surface by men who fish the Northern Cape Breton Offshore, come from a depth of some 160-210m. The samples themselves have a range in sizes from a few cm^3 to $>1m^3$. Although most of the larger samples are thrown back over the side, several of the smaller more portable samples are kept. One man has accumulated enough carbonate mounds to build a wall for his yard, as seen in Figure 1.2 in chapter 1 and partially reproduced here showing one of the large specimens. A fisherman recalls bringing up 21 samples in 2002 (personal communication, Wallace 2006).

Figure 3.1: Shows a large carbonate mound in the wall built by a local fisherman, Bay St. Laurence. The wall is approximately 1 meter high and the single specimen reaches that height. Most specimens as seen surrounding the centre objects are smaller.

Harrington (2003) explained that each of the carbonate mound samples studied had an interior that showed they were cemented together by fine grained micrite cement. Harrington also described the three different textural forms a carbonate mound can take. The carbonate mounds of offshore Cape Breton Island should be broken in to three types, “popcorn”, layered, and erosional textures (Harrington, 2003). The three sub-groups are based on exterior characteristics of each specimen that Harrington viewed.

The popcorn textures refer to the dendritic and bulbous masses that cover the exterior of the mounds. The popcorn nature can be seen in Figure 3.2, and shows a distinct rough or hackly texture to the exterior of the mound. The carbonate mounds that fit in the “popcorn” type also displayed agglutinated muds with some erosional pores (Harrington, 2003). Harrington’s (2003) description of the popcorn structure itself suggests that each individual popcorn is only millimetres in size, and of the 6 mounds he looked at covered as much as 60% of the mounds that fit in to this classification. The popcorn nature can also be seen in Figure 3.3 (a layered mound) but here the sample is principally layered.

The layered textured mounds refer to the preservation of bedding during the carbonate mound buildup. Although Harrington does not use the term layered, it is what he is referring to when he discusses the muddy type. Harrington defines this type by the homogeneous nature of the muddy layers that have a thickness of 1-2cm as seen in Figure 3.3.

The erosional texture is the result of erosional processes and mounds with this texture show rounded edges as well as a high degree of porosity. Harrington (2003) says that the porosity in the mounds was in excess of 60%, shown in Figure 3.4.

In addition to those three there is another key structure to the mounds that was unavailable at the time of Harrington's work. The hydrocarbon vents, an example shown in figure 3.5, are the way the excess hydrocarbons get transferred out of the mounds into the surrounding sea water. The structures measure several cm in diameter and have a very circular bowl-like nature. The vent is the linking factor between the 3 types of mounds.

The bio-ecology of the mounds includes several organisms, including those sampled for use in isotopic examination. Pelecypods (bivalves), gastropods, brachiopods, echinoids (spines), brittle stars, foraminifera, serpulid skeletons, arctic boring clam, chitinous worm tubes and thin needle-like unidentified calcite worm tubes are all present and are part of the mound structure. The sole fish that inhabit this region are also part of this ecosystem, although the extent remains unknown.

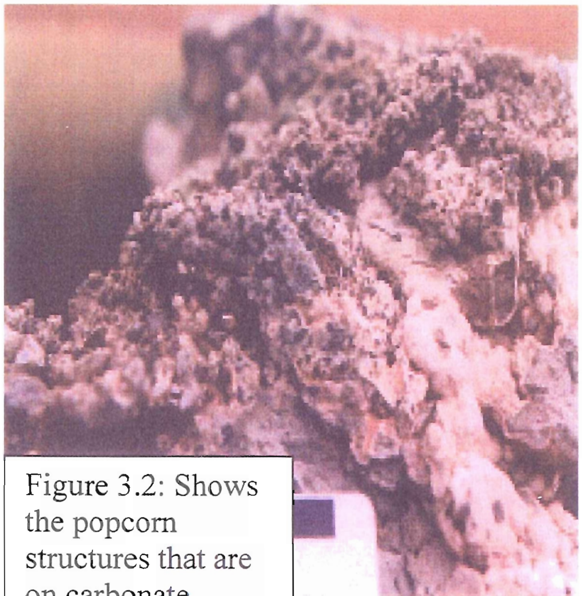

Figure 3.2: Shows the popcorn structures that are on carbonate mounds (Harrington, 2003)

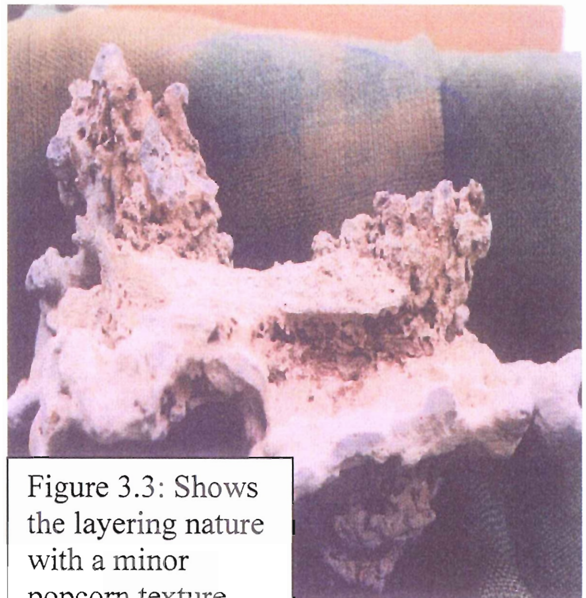

Figure 3.3: Shows the layering nature with a minor popcorn texture. (Harrington, 2003)

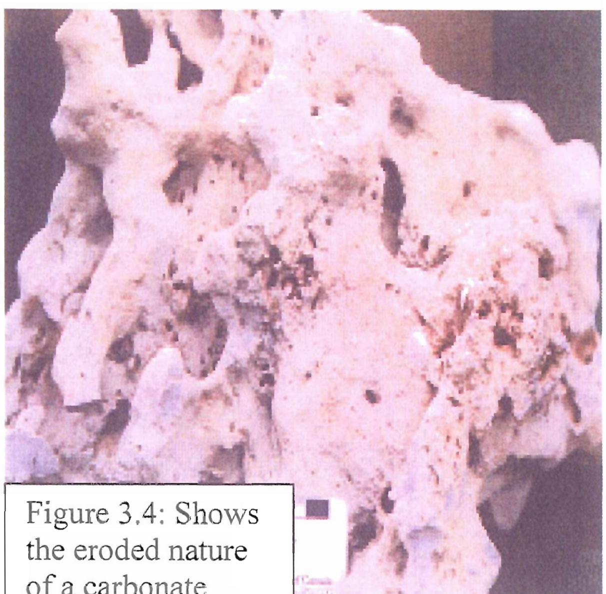

Figure 3.4: Shows the eroded nature of a carbonate mounds hydrocarbon. (Harrington, 2003)

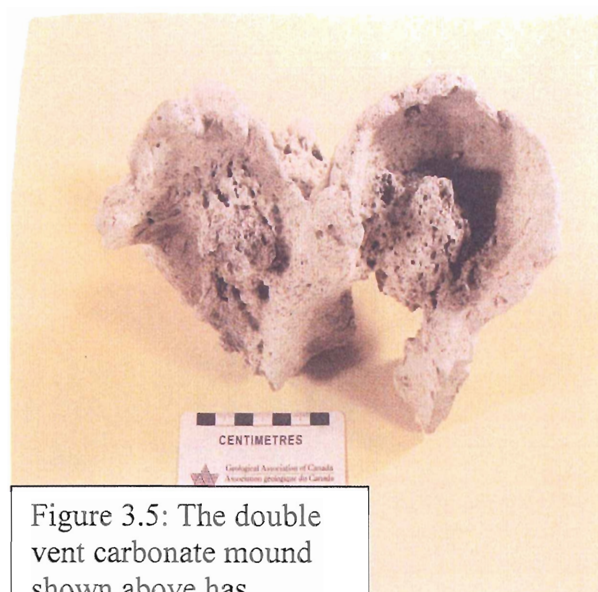

Figure 3.5: The double vent carbonate mound shown above has circular bowl-like vent structures with a core that is substantially more porous then the surrounding mound.

3.3 Isotope Sample Data:

Samples were prepared using the methods described in Chapter 1. The type of shell/organism, the sample weight, as well as the code used for each sample is given in Table 3.1.

Sample Code	Sample Name	Weight of Sample for analysis
CSL – 05 – 01	Pelecypod	63.5 mg
CSL – 05 – 02	Pelecypod	58.0 mg
CSL – 05 – 03	Quahog-Pelecypod	46.0 mg
CSL – 05 – 04	Brachiopod	56 mg
CSL – 05 – 05	Pelecypod	46 mg
CSL – 05 – 06	Pelecypod	45 mg
CSL – 05 – 07	Calcareous algae	40 mg
STD	Coral Sample	69 mg

Table 3.1 Sample codes, organism and weights

Tables 3.2 and 3.3 show the values that were produced for $\delta^{13}C$ on November 29 (Table 3.2) and November 30 (Table 3.3). Although values for $\delta^{13}C$ and $\delta^{18}O$ were determined during the isotopic analysis, the values for $\delta^{18}O$ were not meaningful because during the process the samples were burnt in atmospheric O_2 to produce CO_2 and subsequently contaminating the oxygen isotope values.

Sample Code	Weight used (mg)	$\delta^{13}C$ Results (‰PDB)	Corrected ^{13}C Results (‰PDB)
CSL – 05 – 01	0.09	-10.74	-10.49
CSL – 05 – 02	0.10	-15.94	-15.69
CSL – 05 – 03	0.11	-9.01	-8.76
CSL – 05 – 04	0.09	-20.57	-20.32
CSL – 05 – 05	0.09	-19.53	-19.28
CSL – 05 – 06	0.10	-11.79	-11.54
CSL – 05 – 07	0.09	-57.55	-57.30
STD	0.11	-4.24	-3.99

Table 3.2 Values of $\delta^{13}C$ for samples run on November 29th, 2005.

Sample Code	Weight used (mg)	$\delta^{13}C$ Results (‰PDB)	Corrected ^{13}C Results (‰PDB)
CSL – 05 – 01	0.38	-10.99	-10.40
CSL – 05 – 02	0.43	-14.52	-13.93
CSL – 05 – 03	0.46	-9.05	-8.46
CSL – 05 – 04	0.35	-35.86	-35.27
CSL – 05 – 05	0.48	-26.43	-25.84
CSL – 05 – 06	0.39	-10.00	-9.41
CSL – 05 – 07	0.53	-61.97	-61.38
STD	0.42	-4.03	-3.44

Table 3.3 Values of $\delta^{13}C$ for samples run on November 30th, 2005.

The samples were run with a standard which is labelled STD in Tables 3.2 and 3.3. The values produced for this STD sample are clearly the least negative.

The standard used is a piece of coral (Risk et al 2003) in which the $\delta^{13}C$ value was determined using a non-combustion (in a vacuum) method. Here it was used to check the accuracy of the combustion technique by comparison of the values from the two methods. Using a standard isotope analysis the $\delta^{13}C$ on the STD, the value obtained was -2.5 ‰PDB (Risk et al 2003). This result is not perfect but still compares very well with these values, that averaged -3.7‰PDB,which validates the technique.

3.4 Seismic Interpretation:

The seismic section supplied by Bedford Institute of Oceanography (BIO), location shown in Figure 3.6, of the Cape St. Lawrence area, shows several key features. The features included are columnar release, bright spots, seismic turbidity and seismic diapirs. The seismic sections also show surficial and bedrock geology.

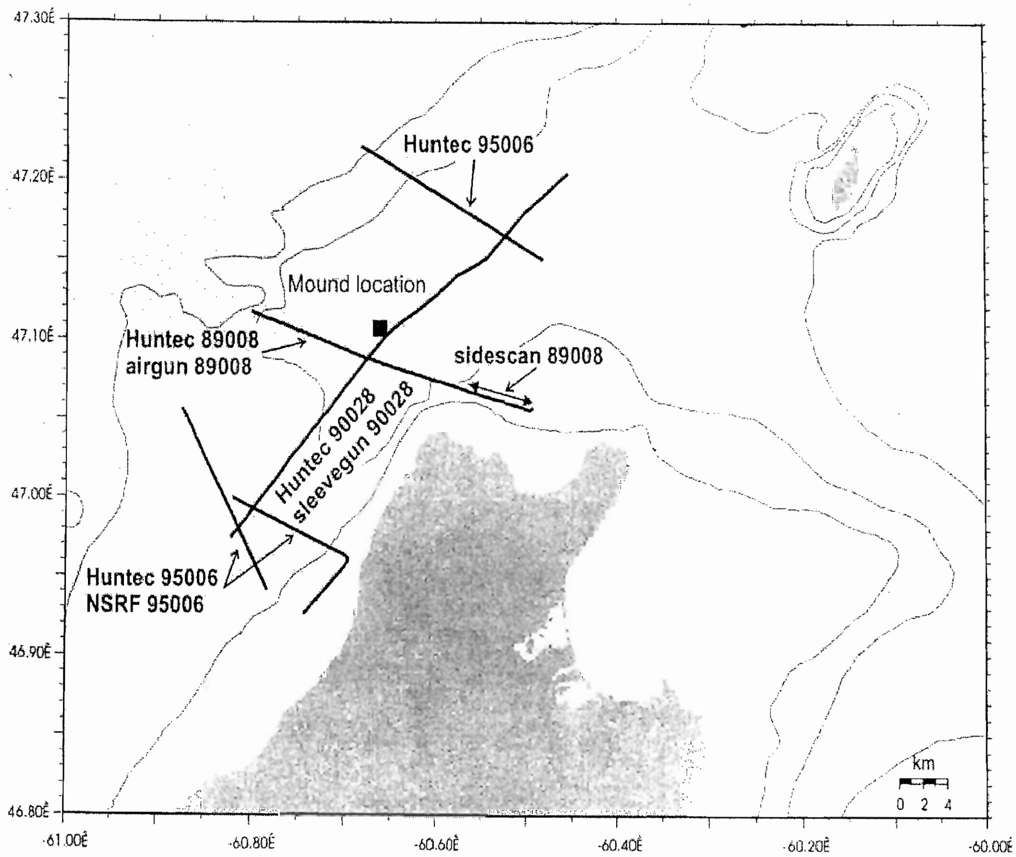

Figure 3.6 shows the locations of the seismic lines run by the Bedford Institute of Oceanography and the location of the carbonate mounds. Note: NSRF, sleevegun and sidescan records not used here. The important lines to this study are 95006, 90028 and 89008.

Figure 3.7 shows a section of the 89008 Huntec seismic lines provided by BIO showing a columnar disturbance emanating from what is interpreted to be bedrock, which could indicate a fault. The black arrow indicates the columnar disturbance, notice that the beds dip down towards the source of the gas, and in some places show truncation due to the possible out gassing of hydrocarbons. The trapped gas has a lower density than the layers that overlie it; this allows the gas to migrate towards the surface. The vacant space left after the transfer is then infilled by the superseded sediments. This is the best example of hydrocarbon outgassing available in the 89008 seismic sections, however it is not the only example.

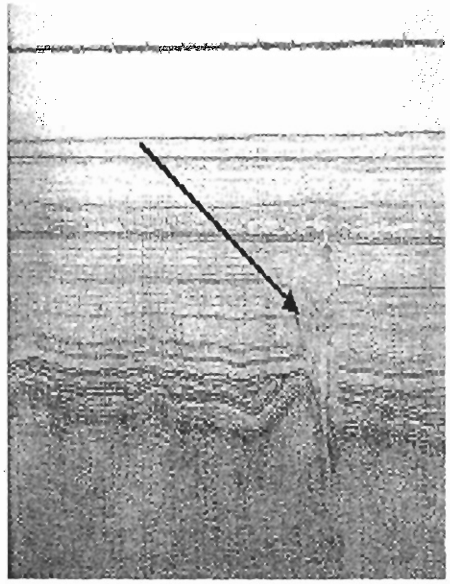

Figure 3.7: Columnar Hydrocarbon release, from the 89008 Huntec seismic lines.

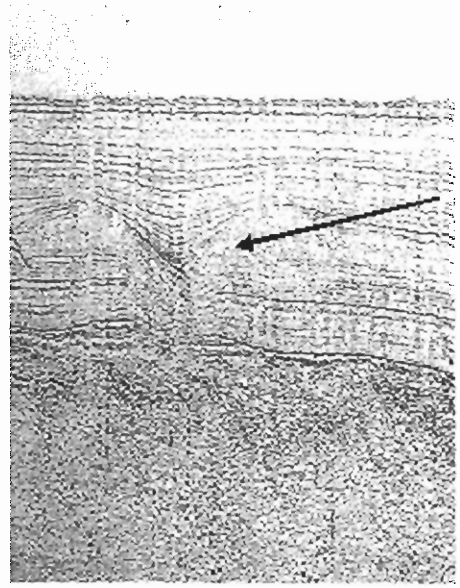

Figure 3.8: Bright spots indicated by the arrow, 89008 Huntec seismic lines

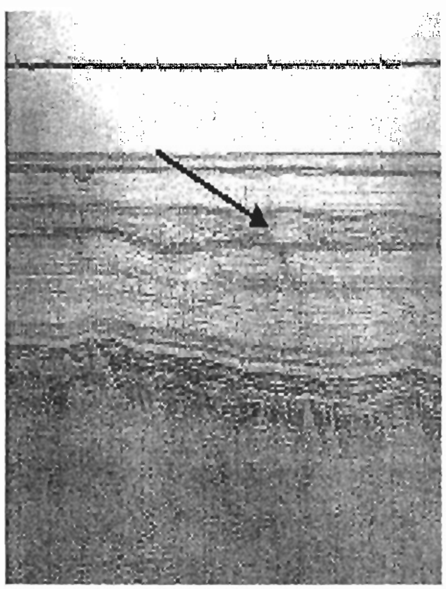

Figure 3.9: Possible Diapir indicated by the arrow, 89008 Huntec seismic lines

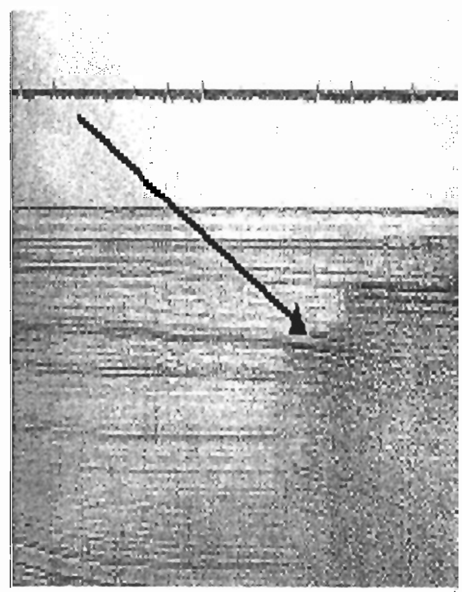

Figure 3.10: Acoustic Turbidity indicated by the arrow, 89008 Huntec seismic lines

Another key feature are the bright spots which have a look of caving in of the sediment layers much like the columnar structures. This is due to the presence of trapped hydrocarbons. Figure 3.8 from Huntec line 89008 shows a section in a layer known as a bright spot, which is an amplified anomaly in the sediment layers caused in this case by the trapping of hydrocarbon, and shows up on the seismic lines because of the change in acoustic impedance.

A third feature that is dispersed through the seismic sections are "diapir" structures. They resemble a ballooning of the sediment layers and are common in the less deep sediments, but are not exclusive to them (Figure 3.9 from Huntec line 89008).

Although the massive outgassing is a dominant feature, there are smaller features also associated with the seismic lines. One of the seismic lines has a section where the beds while clearly distinguishable for a portion of the seismic line abruptly becomes distorted; this is an example of seismic turbidity. This turbidity section of the seismic record resembles land version of glacially deposited material which coupled with what is known already about the geology of the area can imply that it was deposited during the last glacial period, with the more recent sediments still overlaying (Figure 3.10). Most of Huntec line 90028 and part of 89008 is made up of sections affected by seismic turbidity.

Huntec line 89008 shows bedrock coming up in hill like structures that have incised channels between them. These channels are filled with recent sediments. Figure 3.11 shows this section of line 89008 and has clear bedrock hills indicated by the yellow arrow and valley fills indicated by the red arrow.

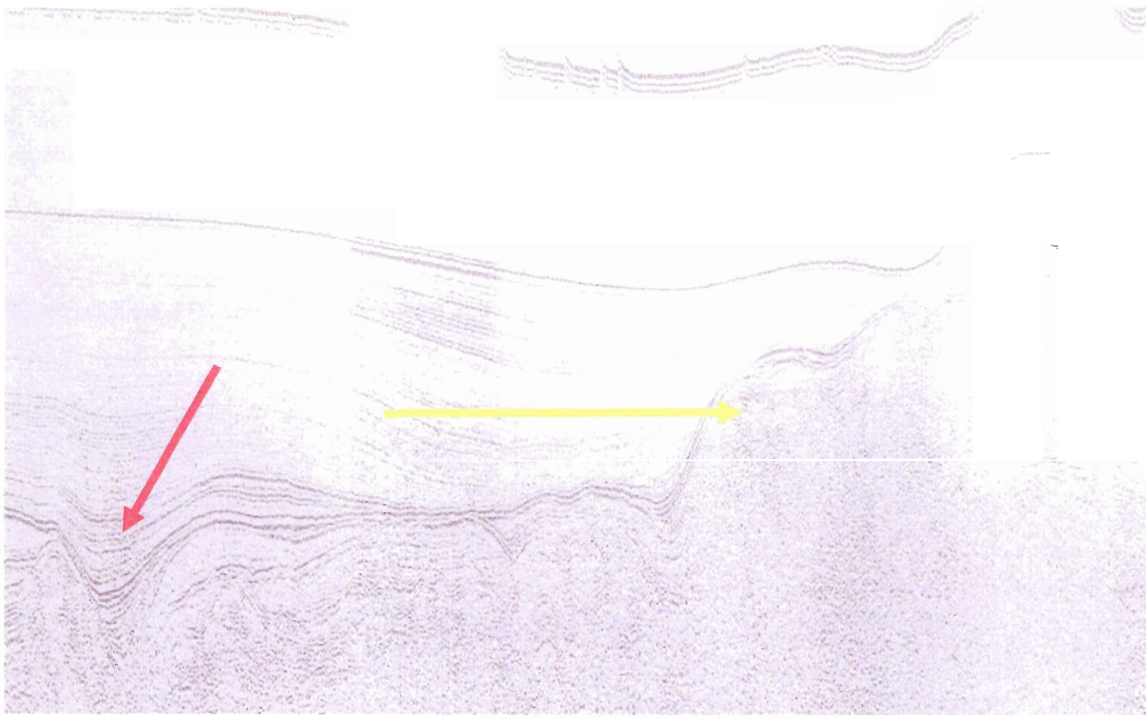

Figure 3.11: Shows the Huntec seismic line 89008 from the Bedford Institute of Oceanography. The yellow arrow shows the bedrock hills, and the red arrow shows the channel filled material.

Chapter 4: Discussion

4.1 Significance of Isotope Data and Seismic Interpretation: Source of Hydrocarbons:

4.1.1 Isotope Data:

By comparing my isotopic data to that of Roberts (1998) and Carpenter & Lohmann (1998) it becomes clear that most of the ^{13}C values for the carbonate mounds faunas fall within the "seep-related carbonates" section or just outside it and are not related to normal sea water carbon values. This implies that the carbon can potentially come from methenogenesis of hydrocarbon for the offshore Cape Breton Island carbonate mounds. If the shells were formed in normal sea water their isotopic values should be closer to that reported by Carpenter and Lohmann (1998).

4.1.2 Seismic Interpretation:

There are several key features to be discussed from the interpretation of the seismic lines and their implications on the possibility of the hydrocarbon source being either bedrock or recent sediment, and whether vents or seeps exist.

- The first of these key features is the columnar sediment disturbance that comes from the bedrock. The significance of this structure is that it shows a potential hydrocarbon flow from bedrock in to the recent sediment layers. This shows that the hydrocarbons that form the carbonate mounds are at least in part supplied from a bedrock source.
- Figure 3.8 is an example of a bright spot, which has a significant role in the model of formation. This small trapped hydrocarbon reservoir will not last

forever especially in this unconsolidated sediment area, the release of the material over a period of time could result in the formation of the carbonate mounds in question or a pock mark structure. Where the hydrocarbons originated from is hard to tell in Figure 3.8 due to bottom of the conic bright spot resting just above the bedrock layer.

- Figure 3.9 shows a section of the seismic line that has a diapir-like structure contained in the sediment layers. This indicates a section of trapped hydrocarbon that may be the remnants of a minor up gassing event of hydrocarbon released from the bedrock that was trapped at this depth or it could be that this layer managed to hold a certain amount of hydrocarbon since burial and this is where it has accumulated. Classic diapirs are indicators of methylhydrates but at this shallow depth this is unlikely. The more likely situation is that these diapirs are just modified bright spots and therefore fit well with the model of formation.
- Figure 3.10 shows a portion of a Huntec seismic section, part of line 90028, that changes into acoustic turbidity, however not entirely, which is caused by the presence of hydrocarbons trapped in the layers, Hoveland et al (1998) suggest >7% gas in sediment leads to this signature. The layers appear to disappear, however this is only because with the inclusion of hydrocarbons it becomes difficult to impossible for the seismic signal to determine the differences in layers due to the similar densities of the layers.
- Figure 3.11 is from the Huntec line 89008 and shows bedrock coming up in hill like structures that have incised channels between them. These channels have been filled in with sediment, this agrees with what Josenhans (1999) said

about the area. The seismic lines that have been looked at seem to coincide with Josenhans geological interpretation. This validates the interpretation and the procedures used.

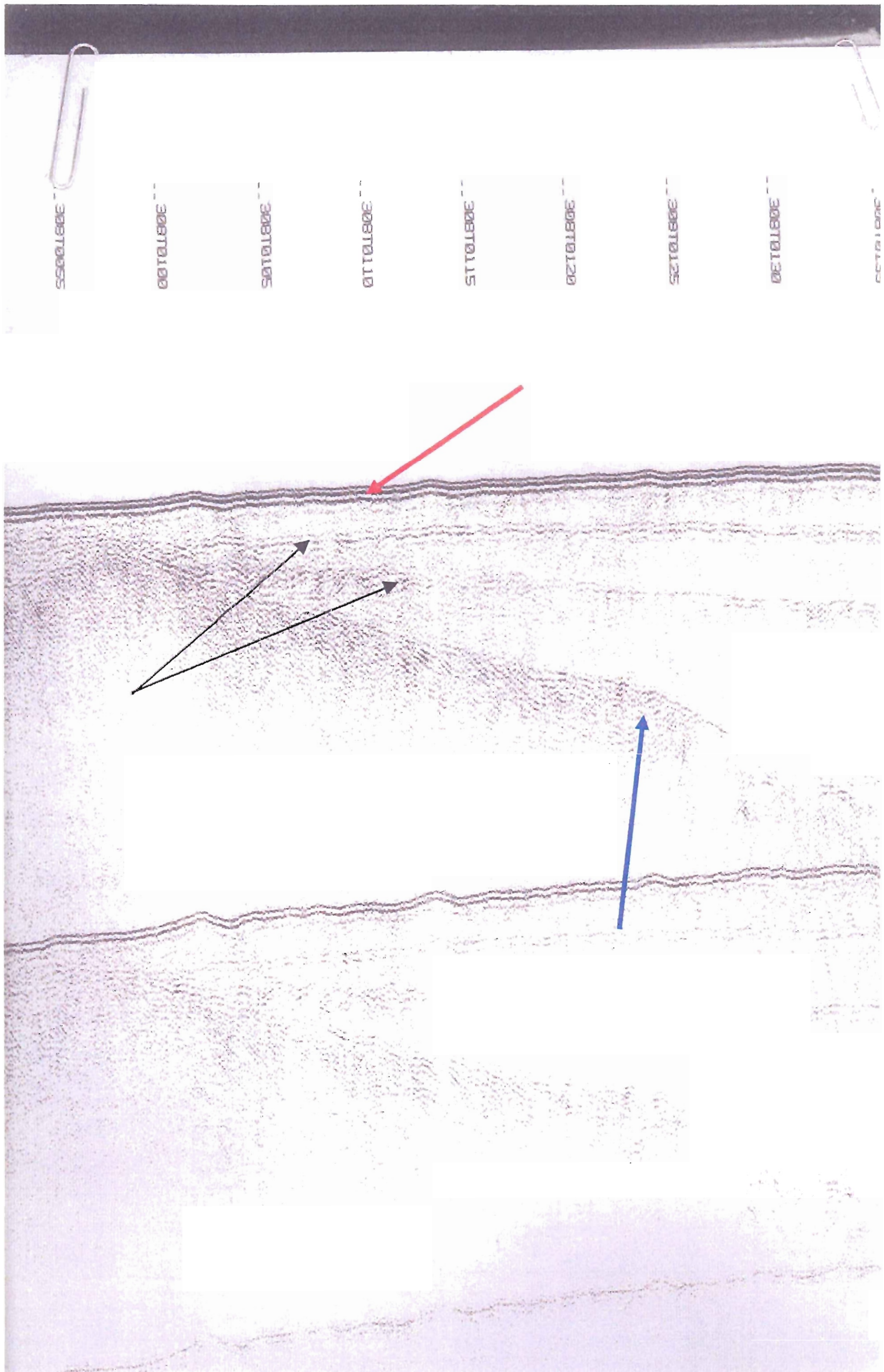

Figure 4.1: Till layers indicated by the black arrows are stacked on top of each other but end against a section of seismic retardation. The red arrow indicates a layer of unconforming material, the blue arrow indicates possible bedrock underneath the recent sediments, which seems to be wedged by a possible layer of till. From line 90028.

The carbonate mounds that are found offshore of Cape Breton Island are unique in some respects to carbonate mounds found in the rest of the world. Other carbonate mounds have also been found in the Caribbean and in the North Sea. Both of these types have some similarities but are generally much larger in size and scope. This implies a greater supply of hydrocarbons or a bigger volume of marine muds, or more likely, the combination of the two. Although the carbonate mounds from the Caribbean and North Sea are dissimilar to those considered in this research, there is another area where similar mounds have been located. Grant et al (1986) discusses a carbonate mound found that is strikingly similar from the Baffin shelf. Grant et al. suggest that these mounds were manufactured around a fissure in the seafloor that was releasing hydrocarbons. Grant's mound formation idea seems to coincide well with the speculation to the origins of the offshore Cape Breton Island specimens. The figure of the carbonate mound that Grant used in his paper compares very well to those of the carbonate mounds found by local Cape Breton fisherman (Figure 4.2). The similarities in both mounds suggest that they are formed in an analogous manner. Note that the mounds Grant found were at depths of 360-430m and associated with a well recorded oil seep where as those in question in this paper are at 210m depth into no recorded oil showing at the seafloor.

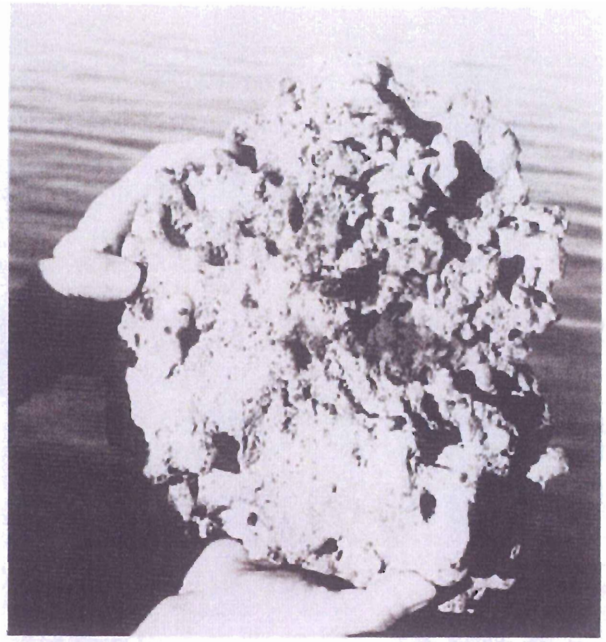

Figure 8.3. Photograph of sample of crust formed around fissure in the seafloor (by R. Belanger).

Figure 4.2: Two carbonate mounds, left from Cape Breton Island and right from Grant (1986). Using the ruler on the left and the hands on the right as scales notice the similarities in size and shape. Also worth noting is the possible 'popcorn' structures that are visible on both mounds. This suggests that Harrington (2003) 'popcorn' descriptor applies to more then just the mounds from Cape Breton Island.

4.2 A Model for Mound Formation:

From studying the mounds and the literature I have come up with a model for the formation of the carbonate mounds. The formation of the mounds can be broken in to two different paths of formation with one end result to the cycle of formation. I propose that these paths depend on the flux rate of hydrocarbon material that comes from the reservoir.

The first type of formation is due to a high flux rate that is sufficient to mix and disturb the sediments resulting in a dendritic texture to the carbonate mounds. Hovland (1998) shows in Figure 4.3 how a carbonate mound would grow and be constructed at the seafloor if the flux rate is high enough to cause a "stream" of gas and clastic material both at the subsurface as well as in the water column. The exterior of these mounds has "popcorn" like look, where each of the mounds is covered with tiny bud like structures. This happens because of a mixing of sediments and hydrocarbons both above and below the sediment water interface. This structure is shown in Figure 3.2. Hovland's (1998) theory does not match in two respects, the first is that the mound came from a 'pockmark', which is not an absolute comparable environment to that which the carbonate mounds of this study have been found, in that we do not see pockmarks. The second is that the subsurface material is broken into two sections. The first is the cemented sediment that surrounds the second unlithified section of material in the center (Hovland, 1988). This conflicts with the mounds in this study because there is no current evidence to suggest that the mounds have any section that is unlithified. Although the subsurface geology of the 'pockmark' mounds of Hovland's paper do not exactly mesh, the surface structures in the figure appear to fair much better. Section three in the Figure 4.3 shows a section of loosely consolidated material which has a porous nature. Section four is tightly agglutinated material which runs very consistently with the mounds from offshore Cape Breton Island. Another key point to the Hovland figure is the presence of voids, which are frequent on all the samples retrieved from the offshore of Cape Breton Island.

The second type of formation is due to a lower flux rate, this carbonate mound growth is termed layered. The layered carbonate mounds tend to form in a similar nature to concretions such that the original bedding layers are preserved. The layered structure is shown in Figure 3.3. Mozley's (1996) Figure 4.4 shows the concentric formation of concretions in the subsurface sediment. In this situation (model/theory) the hydrocarbons flux rate is slow such that bedding is not disturbed, but there is enough methanogensis that the pore spaces become "clogged" with calcite. In other words the hydrocarbons come up and the sediment layers are preserved, giving the mounds a layered look.

The third type and last stage of a carbonate mound cycle is the no flux environment. Without the flux of hydrocarbons the gradual erosion of the carbonate mound due to natural biological and chemical processes takes the dominate role in mound appearance. This can be seen in Figure 3.4.

A high rate of flux and a non-flux rate are end members to the carbonate mound building process. The moderate flux rate although a middle stage in the growth of carbonate mounds could also be the starting point, after which a higher rate of flux would lead to popcorn textures coupled with layering textures.

These two figures are helpful in the ideas of formation, however both are missing each other to be complete. Figure 4.5 shows the interpretation of what combining both Hovland's and Mozley's figures together would result in. The first section is the above ocean floor portion, 'I' indicates the part of the mound made up of popcorn structures.

This area contains both vent structures and voids in the mound itself. The second section 'II' is the part of the carbonate mound that could develops layers. The small dashed lines indicate the concreting out portion of the mounds growth. The grey arrows in the middle are the feeding hydrocarbons for the mounds and the grey arrow off to the right side indicates the direction of younging sediments. Obviously mound formation is not strictly or exclusively either of these two mechanisms. They can be a combination of both or include another process that has not been determined. Further work on the subject may even lead to the discovery of pockmarks.

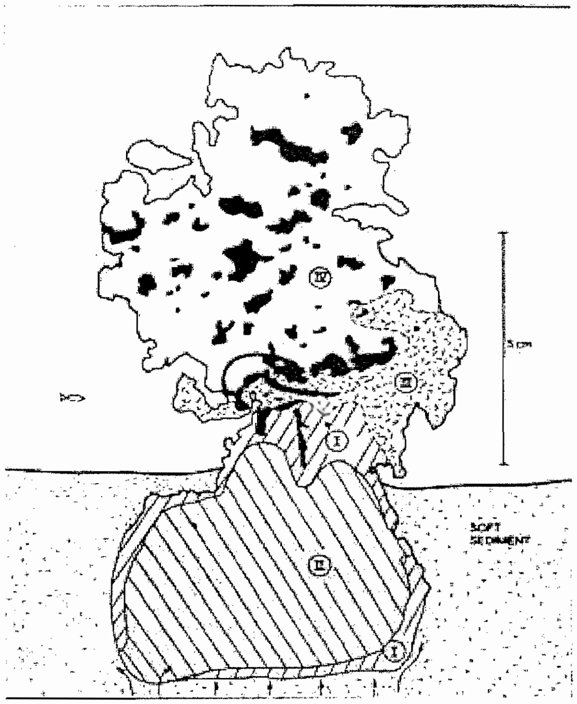

Figure 4.3: Shows Hovland's mound construction, which includes both the surface and the subsurface geology. For the purposes of this paper the subsurface section conflicts with the predicted mound growth for the Cape Breton Island offshore.

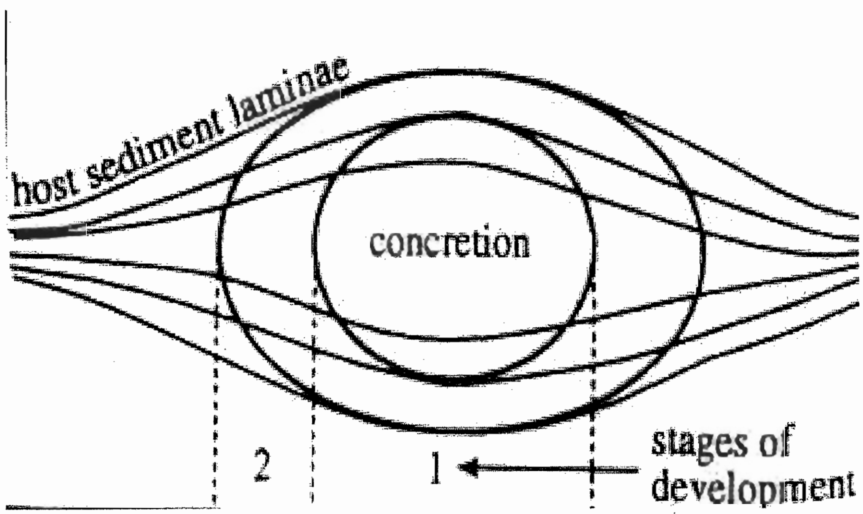

Figure 4.4: Mozley's concentric growth of a concretion using material coming up from depth, which displaced the host laminae as a result.

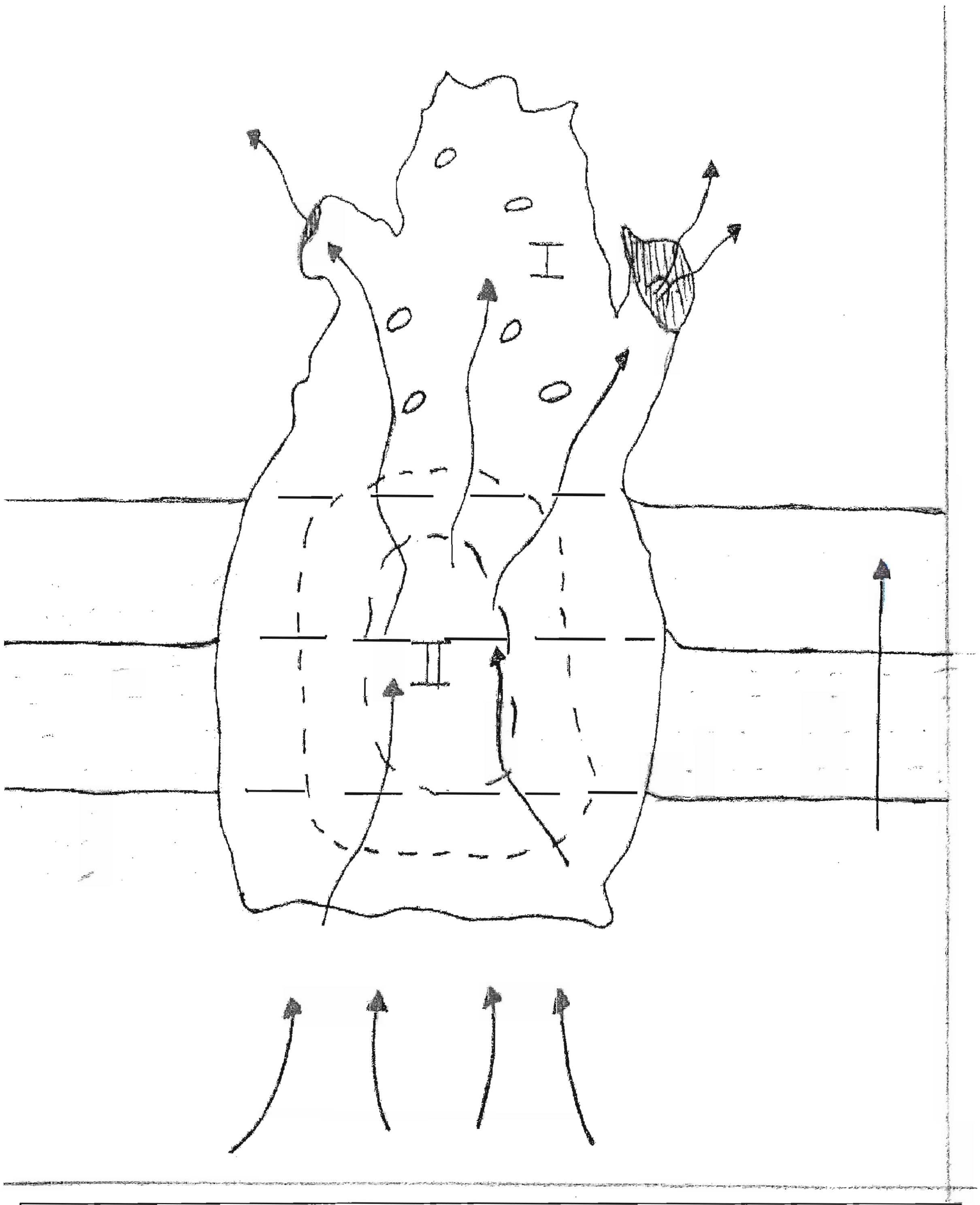

Figure 4.5: The combined figure of Mozley and Hovland. Area 'I' contains vents, voids and the mound. Area 'II' is the layered area of the mound.

The double vent structures shown in Figure 3.5 are also highly indicative of seeps and outgassing. A high flux rate through the vents will lead to the popcorn textures mentioned in chapter 2, while a moderate flux rate will lead to a more layered looking mound and little to no flux will lead the mound to undergo erosional processes. This flux material passes through the carbonate mounds in vents, which are also a recent advance in the study of the Cape Breton Island mounds. The vents transport the hydrocarbons from the base of the mounds to the top and then releases any left over in to the ocean. It is a shame that we cannot see these structures in situ and whether the vents are separate or associated with one of the two models.

Chapter 5: Conclusions:

Isotopic data supplied from the IRMS lab at St. Francis Xavier University show a distinctly more negative $\delta^{13}C$ value than the current oceanic waters could supply for the mounds. Using this data as a guide it is clear that a seeped source of hydrocarbon somewhere in the subsurface leads to the methanogenesis of the carbonate mounds.

Coupling the isotopic data with the interpretation of the seismic sections lends further evidence to the subsurface supply theory. The bright spots pointed out on the seismic section show that there are indeed trapped hydrocarbons below the surface. This is backed up by the section of the seismic line that shows a high level of acoustic turbidity, where the hydrocarbons are distorting the signal. The most important indicator however is the columnar vent type structure that is contained in the subsurface strata. This structure appears to run straight down to the bed rock, which furthers the idea that the hydrocarbons may materialize from the oil shales of the Horton Group which is under the Windsor Group. Many of these seeps are seen onshore.

The fishing technique being used off the Northern Cape Breton Highlands is dredging and this area seems to be the only place to catch sole. Why the Sole Fish are unique to this area remains to be determined, but it is clear that there is some relation between the fish and the mounds. Whether the relation is just due to a similar depth requirement or that the mounds themselves are part of the food chain that involves the Sole fish remains unknown. Continued use of this fishing technique may soon strain the Sole population.

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- http://www.pc.gc.ca/pn-np/ns/cbreton/images/Laurentian channel.gif – March 11 2006.
- http://danielgray9.tripod.com/CBgeoColor.jpg - March 13 2006.

Appendix A:

Sample Descriptions and Photos

The first shell sampled is from a bivalve contained in a carbonate mound that can be seen in Figure 4.4 in the following pages, under the prefix CSL – 05 – 01. The isotopic data from the results section (Chapter 3) shows that sample CSL – 05 – 01 has a ^{13}C value of -10.45 on average between the two sample runs. This information shows that CSL – 05 – 01 was not formed with ^{13}C material extracted exclusively from the sea water, but rather has a source of ^{13}C that must have been buried beneath the sediments from a time when values of ^{13}C differed from today.

- The second creature sampled is another bivalve contained in a carbonate mound coded CSL – 05 – 02. The mound is still in the process of receiving more ^{13}C from a source that judging by the isotope analysis data results (-14.80 +/- 0.9) is subsurface and buried. The mound itself is probably still receiving ^{13}C from the buried source due in part to what appears to be the "popcorn" looking structures indicated by the red arrow. As previously mentioned this indicates a carbonate mound that is still receiving a high flux in hydrocarbons.
- CSL – 05 – 03 is another bivalve, this sample however is no longer connected to a carbonate mound. The isotope data for CSL – 05 – 03 shows a negative -8.51 +/- 0.15 value for ^{13}C, although this value is slightly less the in the CSL – 05 – 01 and CSL – 05 – 02, it still shows a ^{13}C value that is lower then the current values in the oceans today which is closer to -4. The sample did suffer one through puncture during the extraction of material for the analysis, which resulted in a restart to the sampling, this puncture is indicated by the yellow arrow in Figure 4.6

- CSL – 05 – 04 after analysis showed ^{13}C values that were significantly lower then current values of ocean ^{13}C. The isotopic analysis delivered a value of -27.29 +/- 7.02, which has a large even range. This negative result shows a distinct difference in source of material then other carbonates around the world that are being formed on the seafloor. Figure 4.7 shows the sample and points to two specific unique points by comparison to the other 6 sampled organisms. The first is that the shell if extremely thin and brittle the second is that the inside of the shell was completely infilled with carbonaceous muddy material.
- The fifth of the organisms sampled is another bivalve; this particular organism unlike the one before it has a much harder shell. This in its own way made sampling tough, due to the need to use the dremmeling device exclusively on this sample. Figure 4.8 shows CSL – 05 – 05 which similarly to CSL – 05 – 02 with respects to the white diatoms that are present on the sample. The isotopic value for the ^{13}C of the sample came out to be approximately -22.56 +/- 3.28. Much like CSL – 05 – 04 this is much lower then current sea water ^{13}C values, which suggest a source of ^{13}C that has been buried under the sediments.
- CSL – 05 – 06 is a pelecypod bivalve sample, showing distinct growth lines. The pelecypod shell resisted sampling much more then CSL – 05 – 04 but the shell was not quite as tough as the sample from CSL – 05 – 05. The results from the isotope analysis for the pelecypod is -10.45 +/- 1.065 which is quite similar to the results for CSL – 05 – 01 and is close to both CSL – 05 – 02 and

CSL – 05 – 03. This suggests that the hydrocarbon material that is being used by these four samples must come from a similar source. This however is not guaranteed because the only data we have suggests that ^{13}C values are similar, not whether ^{13}C values have been in that range at more then one time in the geologically recent history.

- The last sample is CSL – 05 – 07 and is a white algal mat. The ^{13}C value returned for the algal mat was a bit surprising in that it is such an outlier by comparison to the rest of the sample data. -59.34 +/- 2.04 is more then double the next most negative result from CSL – 05 – 04. This could either mean that the source of hydrocarbon for this sample is completely different then the source for the rest of the carbonate mounds, or that some how the algal mat is significantly more deficient in modern ^{13}C. This maybe because the bacterial mat receives less normal seawater then the previous samples due to the exposed surface area with relation to the thickness of the material.

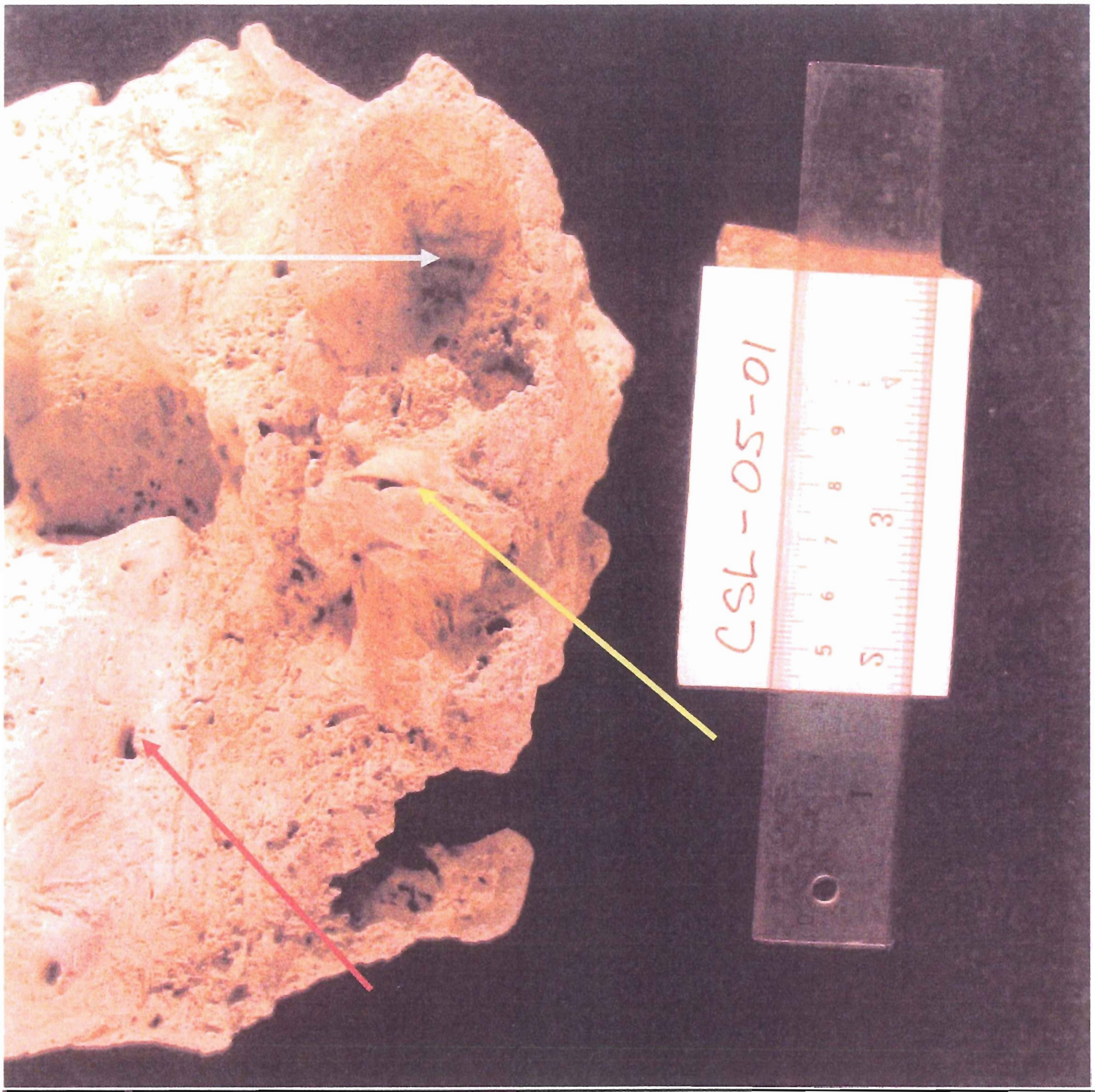

Figure A.1: shows sample CSL – 05 – 01 (indicated by yellow arrow) contained in a carbonate mounds that has an eroded type exterior texture as well as voids (indicated by the red arrow) and a possible extinct vent (indicated by the grey arrow).

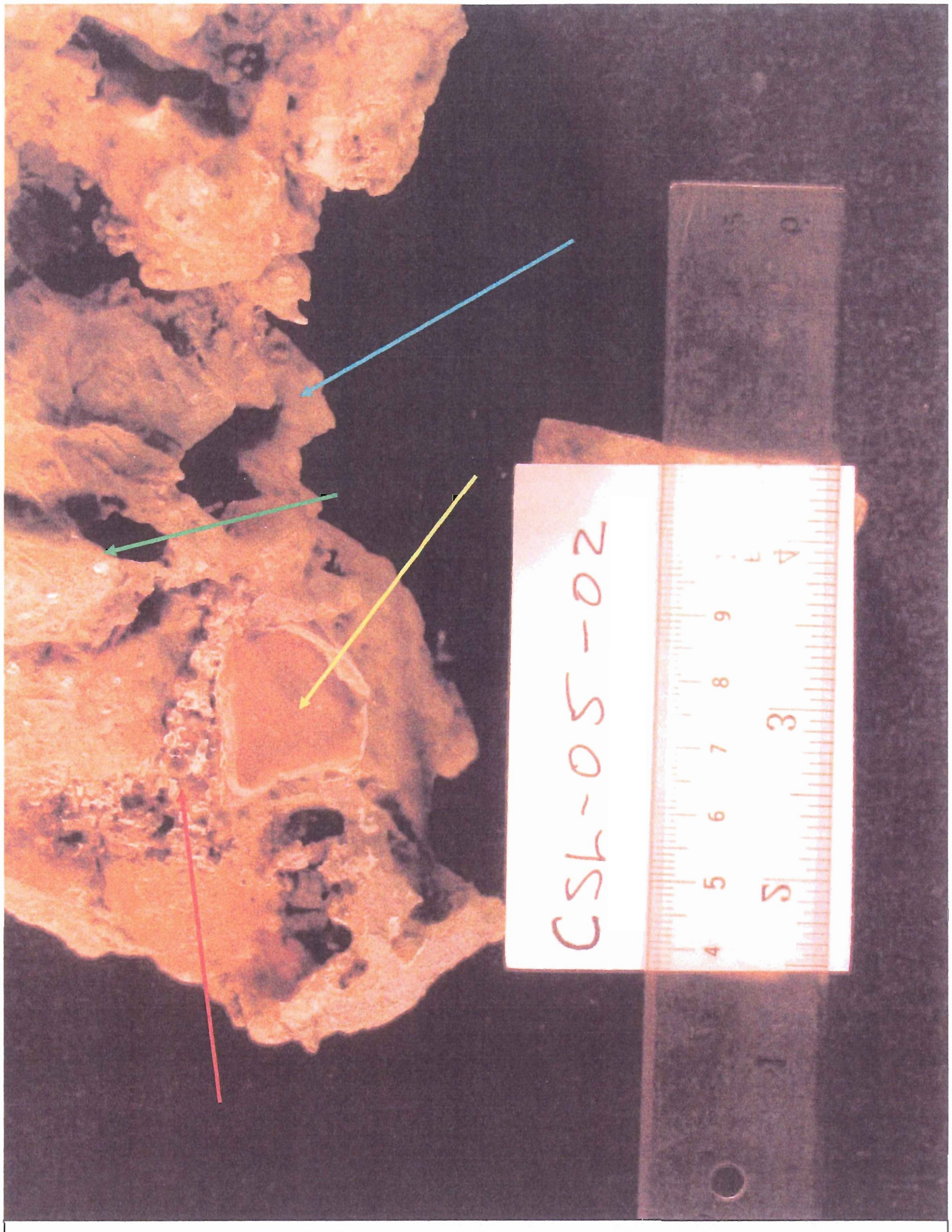

Figure A.2: shows sample CSL – 05 – 02, which is from the inside of a bivalve, the carbonate mound that this sample is contained in could be either a high flux or a lower flux stage of growth. The yellow arrow indicates the bivalve, the red arrow indicates what could be popcorn structures, and the cyan arrow indicates the mounds sharp edges next to a void area. The green arrow shows white circular tubeworms (serpulids) that are another organism attached to the mound.

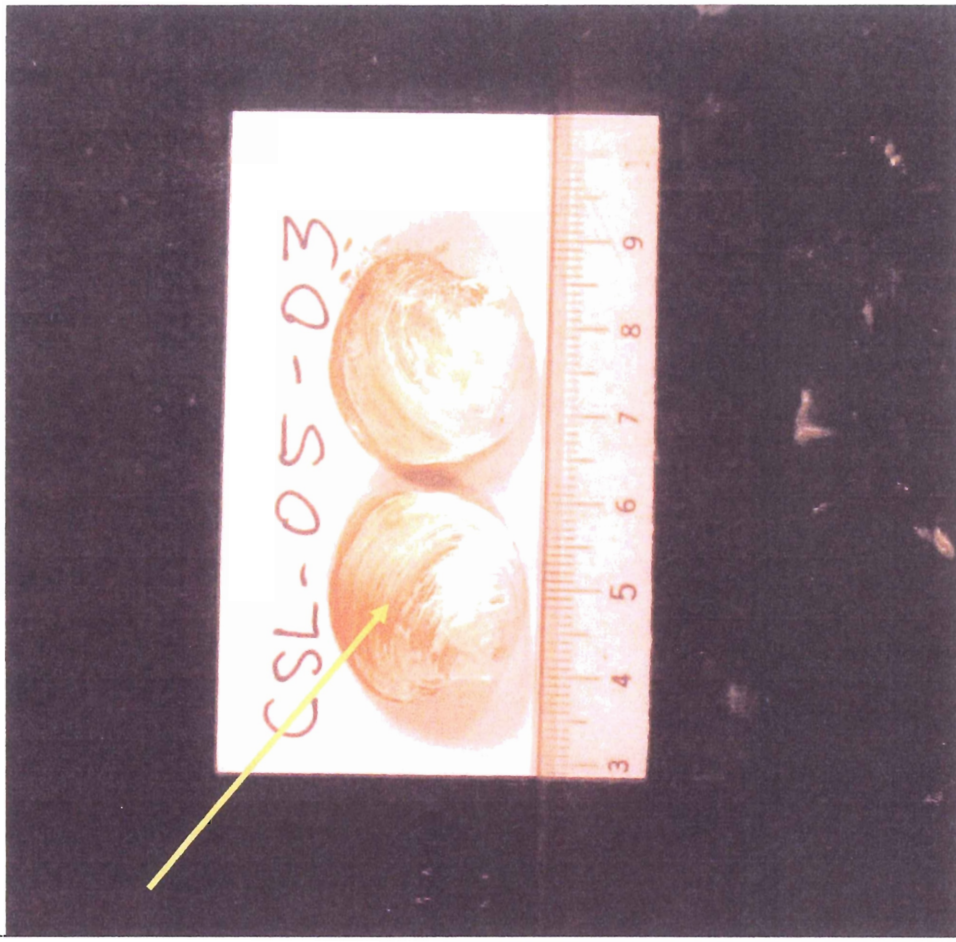

Figure A.3: Shows CSL – 05 – 03 (quahog-type bivalve), each half is 2.5 cm in width. The yellow arrow indicates the section of the shell sampled for the isotope analysis, also the notch in the shell at the edge of the yellow arrow is a puncture point on the shell.

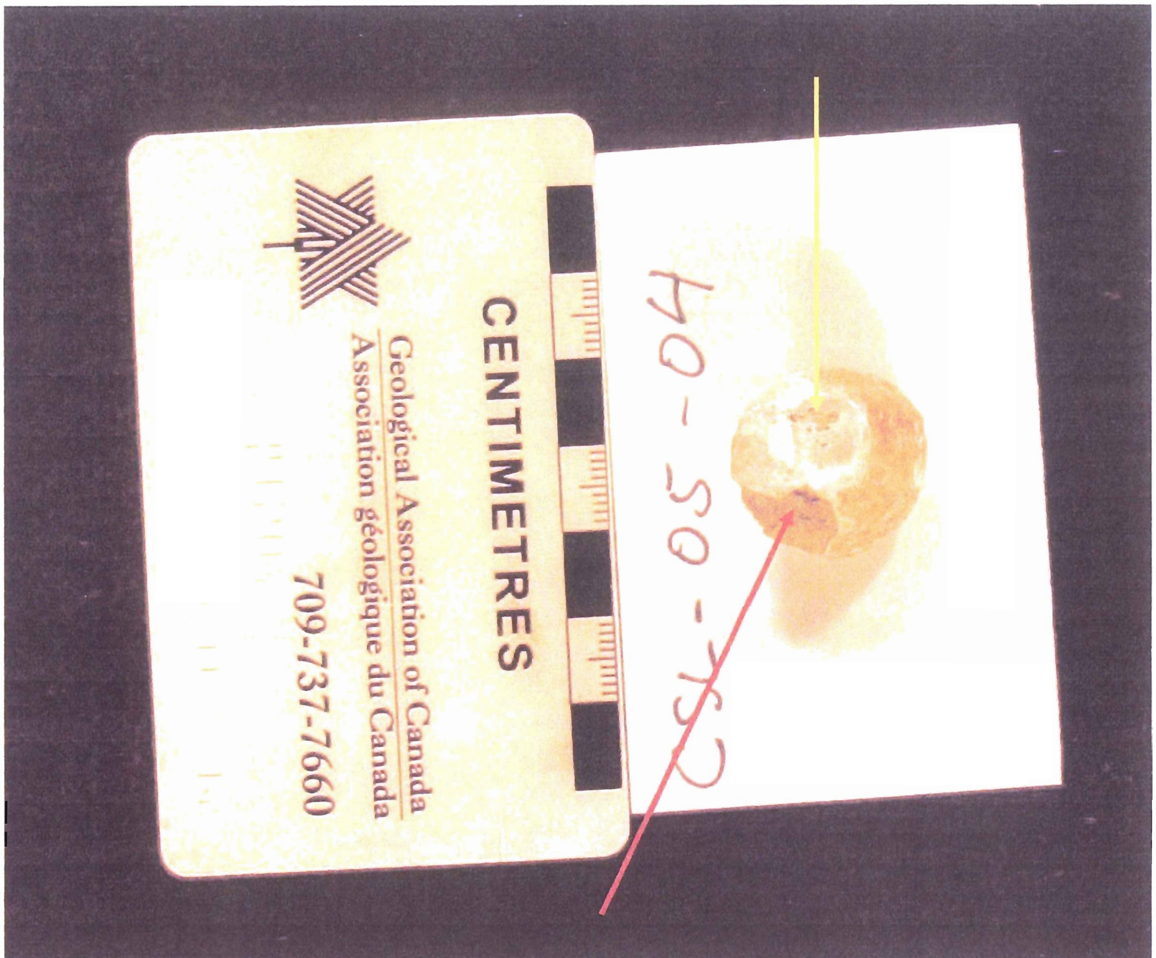

Figure A.4: Shows sample CSL – 05 – 04 separated from the carbonate mound it was retrieved from. The yellow arrow indicates the area of scraping and shows how thin the shell of the creature was because of several small punctures. The red arrow is the material that infilled the shell after the creature's death.

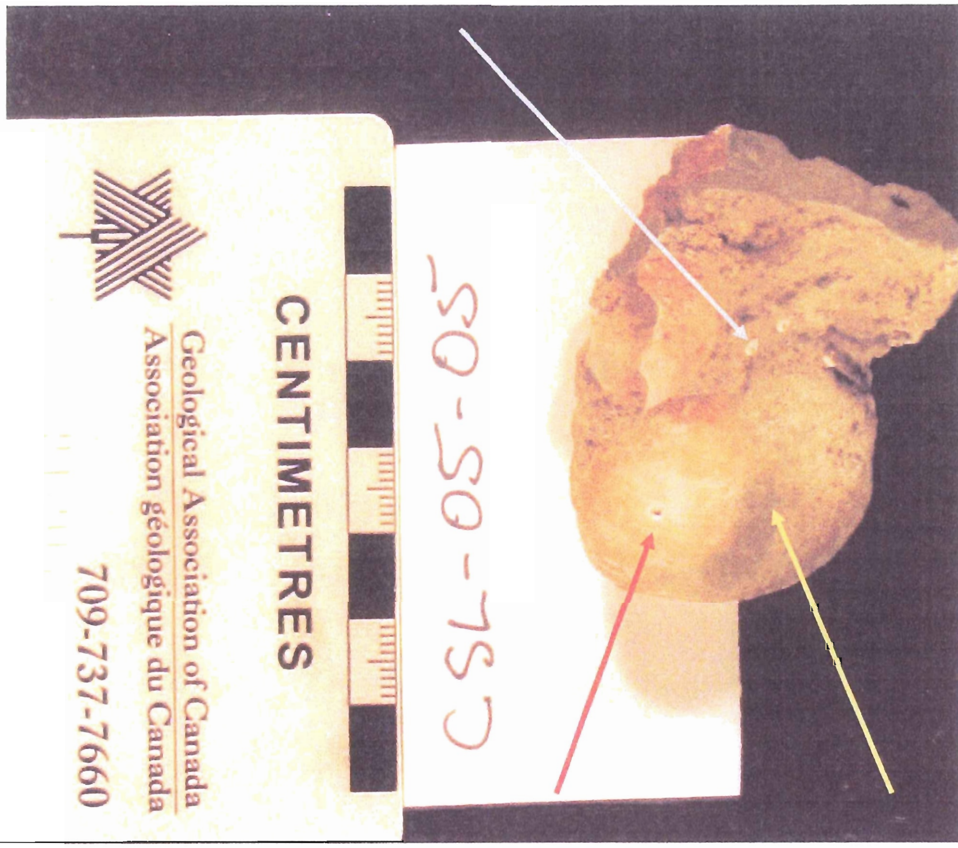

Figure A.5: CSL – 05 – 05 is another pelecypod bivalve sample, indicated by the yellow arrow. The red arrow indicates and area where the dremmel tool, the grey arrow shows the white diatoms that can also be seen in Figure 4.5.

Figure A.6: A pelecypod in the general orbicular shape, the red arrow indicates growth lines for this organism. The yellow area indicates a point where the shell collapsed during the sampling process. The red arrow shows a blown up version of the pelecypod showing the growth lines of the organism.

Figure A.7: Shows sample CSL – 05 – 07 which is an algal mat material indicated by the yellow arrow. The red arrow indicates more of the 'popcorn' structures.

Appendix B:

Excel Sheet for $\delta^{13}C$ Data

Name	Acquisition date	RT (Sec)	Height (nA)	Type	Weight (mg)	13C	13C corrected to NBS18
Blank Nov29 01.raw	29/11/05 16:12	218.3	0.18	Blank	0.00	-25.64	
Blank Nov29 02.raw	29/11/05 16:19	217.8	0.27		0.00	-30.49	
NBS18 Nov29 01.raw	29/11/05 16:26	217.4	4.68	Analyte	0.09	-5.18	-4.93
NBS18 Nov29 02.raw	29/11/05 16:32	217.2	4.67	Analyte	0.11	-5.40	-5.15
NBS18 Nov29 03.raw	29/11/05 16:39	217.2	4.63	Analyte	0.10	-5.18	-4.93
CaCO3 std 01.raw	29/11/05 16:46	217.2	4.56	Analyte	0.11	-4.92	-4.67
CSL 1.raw	29/11/05 16:52	216.8	4.48	Analyte	0.09	-10.74	-10.49
CSL 2.raw	29/11/05 16:59	216.8	4.44	Analyte	0.10	-15.94	-15.69
CSL 3.raw	29/11/05 17:05	216.8	5.28	Analyte	0.11	-9.01	-8.76
CSL 4.raw	29/11/05 17:12	217.1	2.36	Analyte	0.09	-20.57	-20.32
NBS18 Nov29 04.raw	29/11/05 17:19	216.7	4.69	Analyte	0.09	-5.10	-4.85
CaCO3 std 02.raw	29/11/05 17:25	216.9	4.44	Analyte	0.11	-4.27	-4.02
CSL 5.raw	29/11/05 17:32	217.1	3.44	Analyte	0.09	-19.53	-19.28
CSL 6.raw	29/11/05 17:38	217.5	5.13	Analyte	0.10	-11.79	-11.54
CSL 7.raw	29/11/05 17:45	217.0	3.90	Analyte	0.09	-57.55	-57.30
NBS18 Nov29 05.raw	29/11/05 17:52	217.2	4.03	Analyte	0.09	-5.16	-4.91
CaCO3 std 03.raw	29/11/05 17:58	217.1	4.39	Analyte	0.11	-4.20	-3.95
Analysis with dilutor							
Blank Nov30 01.raw	30/11/05 12:27	262.9	0.03	Blank	0.00	-28.79	
Blank Nov30 02.raw	30/11/05 12:34	262.8	0.03	Blank	0.00	-26.31	
NBS18 Nov30 01.raw	30/11/05 12:41	262.0	3.69	Analyte	0.39	-5.57	-4.98
NBS18 Nov30 02.raw	30/11/05 12:47	262.0	4.10	Analyte	0.44	-5.61	-5.02
CaCO3 std Nov30 01.raw	30/11/05 12:54	262.0	3.79	Analyte	0.40	-3.97	-3.38
CaCO3 std Nov30 02.raw	30/11/05 13:01	261.8	4.29	Analyte	0.47	-4.08	-3.49
Blank Nov30 03.raw	30/11/05 13:08	263.0	0.03	Analyte	0.00	-14.18	-13.59
CSL 7 02.raw	30/11/05 13:14	261.7	5.15	Analyte	0.53	-61.97	-61.38
Blank Nov30 04.raw	30/11/05 13:21	262.2	0.03	Analyte	0.00	-22.30	-21.71
CSL 4 02.raw	30/11/05 13:28	262.1	2.20	Analyte	0.35	-35.86	-35.27
CSL 5 02.raw	30/11/05 13:35	261.8	2.09	Analyte	0.48	-26.43	-25.84
CSL2 02.raw	30/11/05 13:41	261.9	3.41	Analyte	0.43	-14.52	-13.93
CSL 6 02.raw	30/11/05 13:48	261.7	3.08	Analyte	0.39	-10.00	-9.41
CSL 1 02.raw	30/11/05 13:55	261.9	3.53	Analyte	0.38	-10.99	-10.40
CSL 3 02.raw	30/11/05 14:02	261.3	4.48	Analyte	0.46	-9.05	-8.46
NBS18 Nov30 03.raw	30/11/05 14:09	261.6	4.61	Analyte	0.49	-5.72	-5.13

Appendix C:

Table of Descriptions

Sample Number	Description	$\delta^{13}C$ (PDB)
CSL – 05 – 01	Size of the dredged sample = 20cm length, sample is 2cm wide and 3cm in length. Hard pelecypod shell.	-10.45
CSL – 05 – 02	Size of the dredged sample = 25cm length, sample is 2.6cm length and 2.1cm wide. Unaltered pelecypod shell (very pearly texture).	-14.80 +/- 0.9
CSL – 05 – 03	Sample 2.5cm in length and 2cm wide. Unaltered quahog-type pelecypod with think shell	-8.51 +/- 0.15
CSL – 05 – 04	Sample is 2.2cm in length and 2.1cm in width. Brachipod, somewhat recrystallised, thin brittle shell with carbonaicous mud fill.	-27.29 +/- 7.02
CSL – 05 – 05	Contained in mound fragment, sample is 3.6cm	-22.56 +/- 3.28

	wide and 3.3cm in length. Large pelecypod with a semi-pearly shell texture.	
CSL – 05 – 06	Sample is 3.5cm in length and 1.5cm in width. Elongated pelecypod showing growth lines.	-10.45 +/- 1.065
CSL – 05 – 07	White calcareous algal or bacterial matt 2.5cm in width and 4.2+ cm in length.	-59.34 +/- 2.04
Standard	White carbonates coral material, soft texture.	-2 to -2.5

Table of specimens and results from the isotope analysis