MODELING OF A PALEOCENE SUBMARINE CANYON, JEANNE D'ARC BASIN, OFFSHORE NEWFOUNDLAND, TO DETERMINE CANYON FILL LITHOLOGY

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for the Degree of Bachelor of Science, Honours
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ABSTRACT

The Hibernia Paleocene Canyon, located in the Jeanne d'Arc Basin, offshore Newfoundland, was modeled using the BasinMod 1D and BasinMod 2D software packages to determine the lithology of the canyon fill. Petroleum industry 3D seismic reflection data shows positive relief in sediments directly overlying the canyon in the western portion of the 3D survey area; the relief is approximately 70 milliseconds in height and can be seen for over 0.5 seconds (two-way time). The relief gradually decreases easternward until it becomes negative in sediments overlying the widest downslope portions of the canyon. No wells have penetrated the canyon fill. Modeling results suggest that the canyon fill is composed of 60% sandstone and 40% shale, in areas showing positive relief. The positive relief results from differential compaction of the relatively incompressible canyon fill and surrounding shales. Knowledge of the canyon fill lithology is useful in understanding the Early Tertiary sedimentary system in Jeanne d'Arc Basin. A canyon fill composed of a large proportion of sandstone is indicative of a terrestrial origin, i.e. the canyon did not simply fill with shale during a period of transgression.

Key Words: differential compaction, submarine canyon, BasinMod, canyon fill, Hibernia, Jeanne d'Arc Basin

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CHAPTER ONE: INTRODUCTION

1.1 General Statement

A drop in sea level during the Late Cretaceous exposed shelf areas of the western margin of the Jeanne d'Arc Basin, offshore Newfoundland, and resulted in the Base Tertiary Unconformity. Several large submarine canyons eroded deltaic sandstones of the Late Cretaceous shelf, feeding sediments from the shelf to form a wedge and fans on the slope and basin floor (de Silva, 1993). One of these submarine canyons, informally named the Hibernia Paleocene Canyon, is the focus of this thesis. The canyon has been mapped using petroleum industry 3D seismic reflection data collected over the Hibernia Oil Field.

1.2 Hibernia Paleocene Canyon

The 3D seismic survey covers 16 km of the canyon's length (Fig. 1.1). The canyon is easily delineated from the termination of strong reflections such as the Fox Harbour and Otter Bay Members which are otherwise continuous across the section (Shimeld et al., in prep.) (Fig. 1.2). The canyon varies in width from 1.4 km in the western portions of the survey to a maximum of 5.5 km towards the east. Its depth increases to 500 m in the widest portion of the

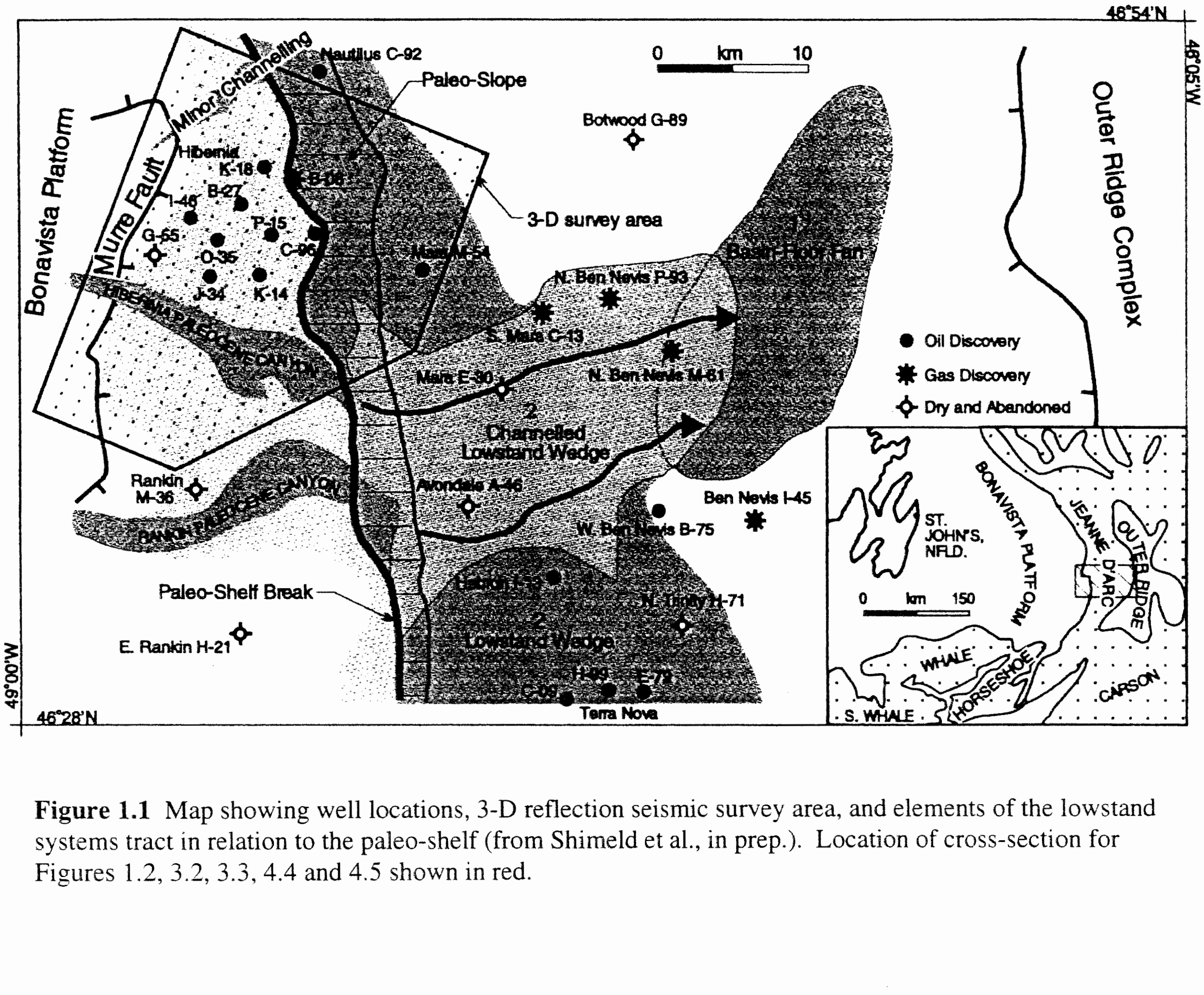


Figure 1.1 Map showing well locations, 3-D reflection seismic survey area, and elements of the lowstand systems tract in relation to the paleo-shelf (from Shimeld et al., in prep.). Location of cross-section for Figures 1.2, 3.2, 3.3, 4.4 and 4.5 shown in red.

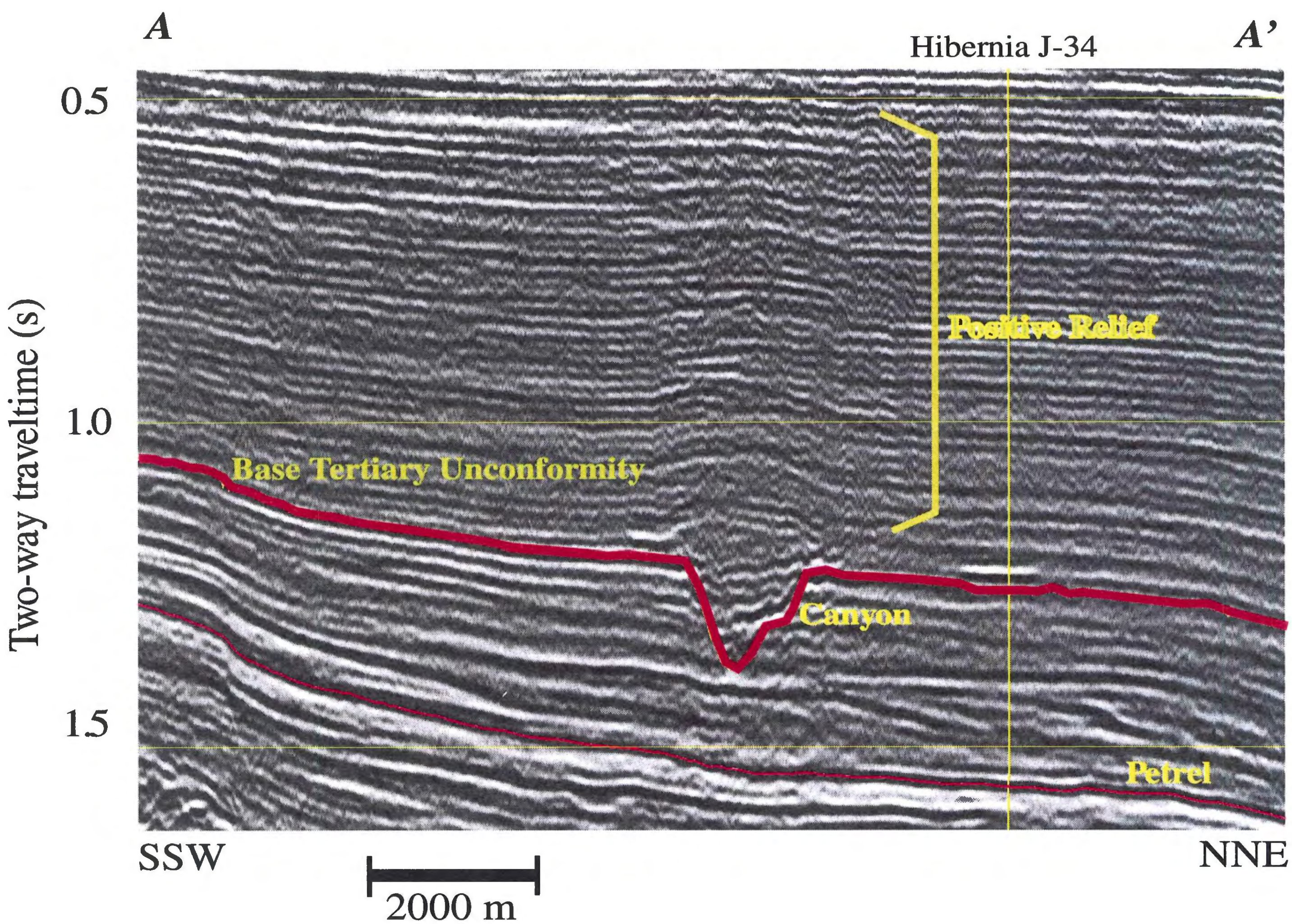


Figure 1.2 Reflection seismic cross section through the Hibernia Paleocene Canyon and Hibernia J-34. Refer to Figure 1.1 for location of cross-section.

canyon (Fig. 1.3).

Relative sea level rise from the Eocene to the present resulted in burial of the canyon by up to 2 km of deep neritic shales, minor chalks, and siliceous mudstones (McAlpine, 1990). The seismic data shows positive relief in sediments directly overlying the canyon in the western portion of the survey area. This positive relief feature is approximately 70 milliseconds in height (two-way time) and can be seen for over 0.5 seconds (two-way time) (Fig. 1.2). The relief gradually decreases towards eastern portions of the survey area until it becomes negative in sediments overlying the widest section of the canyon. No wells have penetrated the canyon fill. The positive relief may suggest that sediments infilling the canyon are incompressible relative to the surrounding formations, whereas negative relief suggests the opposite (Shimeld et al., in prep.).

1.3 Objective and Scope

The objective of this thesis is to determine the lithology of the canyon fill assuming the positive relief observed over the Hibernia Paleocene Canyon is due to differential compaction alone, i.e. shales surrounding the canyon may have compacted significantly more than a coarser grained canyon fill. The canyon system and surrounding formations have been modeled to

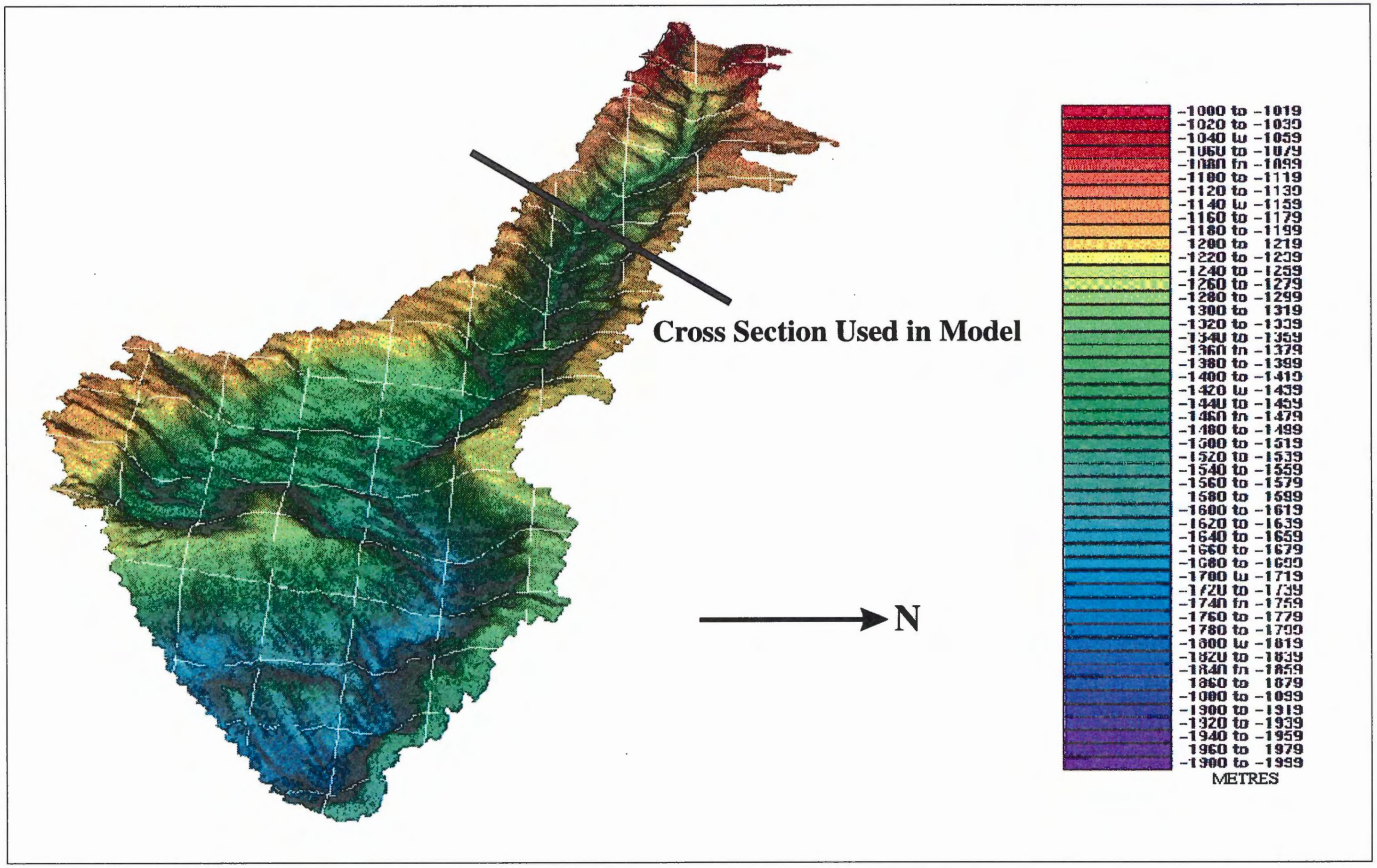


Figure 1.3 Shaded relief, perspective view of the paleo-canyon seismic horizon as an observer would see it looking from the east. Topography, in meters, is indicated by the values shown on the colour bar. The paleo-canyon is mapped for a length of 16 km. At its widest point the canyon is 7 km, while at its narrowest it is 1.6 km. Up to 500 m of sediment are eroded within the deepest portions of the canyon. A meandering thalweg is visible within the deepest portion of the paleo-canyon and records the earliest phase of channel development. Approximate location of cross section used in thesis models shown. Grid line spacing is 1 km (from Shimeld, pers. comm.).

constrain what canyon fill lithologies can account for the positive relief. Knowledge of the lithology of the canyon fill is useful in understanding the Late Cretaceous to Early Tertiary sedimentary system in the Jeanne d'Arc Basin.

1.4 Model Creation

The canyon fill and surrounding formations were modeled in one and two dimensions using the BasinMod 1D and BasinMod 2D software packages from Platte River Associates. Key parameters such as formation age, thickness, lithology, and porosity were obtained from Hibernia J-34 data and input to BasinMod 1D.

Model calculations in BasinMod are controlled by the reduction of pore space due to compaction. To calculate the original thickness of sediments it is necessary to backstrip the model; overlying layers are removed allowing older sediments to decompact. BasinMod removes the effect of compaction by using a compaction equation (Sclater and Christie, 1980), as discussed in Chapter Two. Sedimentation rates can be calculated by dividing the original thickness of the event by the duration of deposition within the event.

Two dummy wells were created in BasinMod 1D; the first lies just outside the canyon, while the second penetrates the canyon fill of a varying lithology. Comparing the decompacted thicknesses between the two wells can help to determine possible canyon fill lithologies. BasinMod 2D was used to extend the modeling procedure to two dimensions. Formations, lithologies, and ages from BasinMod 1D were defined on a reflection seismic cross section of the canyon. The modeling procedure is discussed in detail in Chapter Three.

1.5 Organization of Thesis

Chapter Two gives a broad overview of the tectonic development of the Grand Banks and outlines in greater detail the geology of the Jeanne d'Arc Basin during the Late Cretaceous and Early Tertiary. Submarine canyon systems and sediment compaction are also discussed. Chapter Three presents the geological data from Hibernia J-34 used in BasinMod and describes the modeling procedure. Chapter Four presents and discusses the results of the BasinMod 1D and 2D calculations. Implications for the lithology of the canyon fill are addressed. Chapter Five summarizes the results of the thesis work and presents recommendations for future study.

CHAPTER TWO: GEOLOGICAL BACKGROUND

2.1.1 Geology of the Jeanne d'Arc Basin: Broad Overview

The Grand Banks of Newfoundland overlie five interconnected fault-bounded Mesozoic basins (Grant et al., 1990). These are the Whale, Horseshoe, Carson, Jeanne d'Arc, and South Whale Subbasin (Fig. 2.1). The study area of this thesis is found within the Jeanne d'Arc Basin which is located in the northeastern portion of the Grand Banks. The stratigraphy of the Jeanne d'Arc Basin reflects the tectonic history of the Grand Banks (McAlpine, 1990).

The Grand Banks were subjected to two periods of rifting; the first was the North Atlantic rift which took place in the Late Triassic to Early Jurassic (Sinclair et al., 1992). Continental red beds and marine evaporates and carbonates were the dominant lithologies deposited (McAlpine, 1990). The Grand Banks were tectonically quiet during the Middle to Late Jurassic resulting in the deposition of marine shales and carbonates and a lesser amount of deltaic sediments (McAlpine, 1990). The second period of rifting, which took place in the latest Jurassic to Middle Cretaceous, is known as the Iberia-Labrador rift (Procter et al., 1992). Sand-rich deltaic and estuarine sediments were deposited (McAlpine, 1990).

Deformation and erosion of the Mesozoic basins and surrounding basement rock during

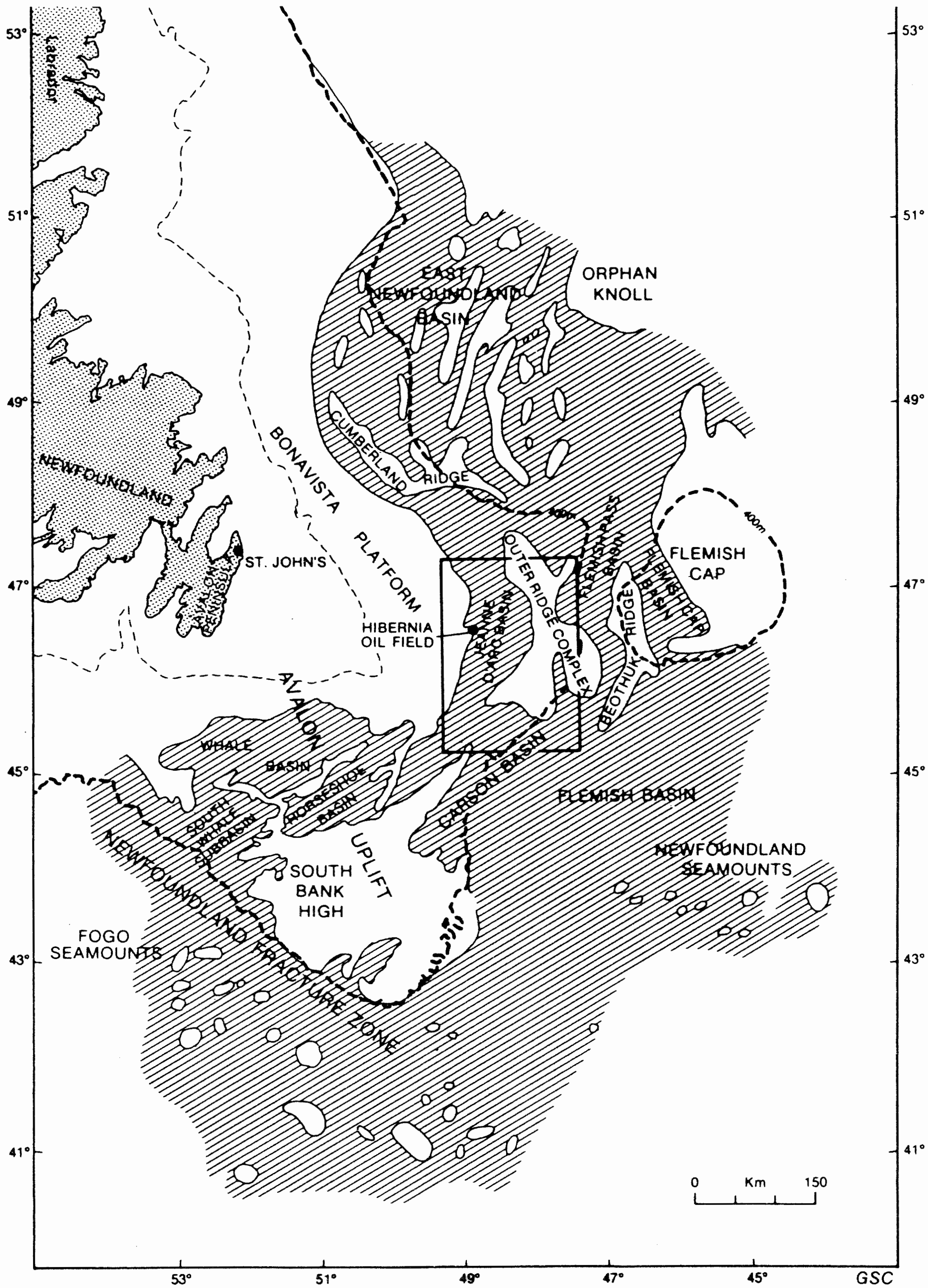


Figure 2.1 Simplified tectonic map showing the principal positive elements and Mesozoic basins (hatched) underlying the continental margin around Newfoundland. Light dashed line is landward edge of Upper Cretaceous-Tertiary sediments. Heavy dashed line is 400-m isobath (from McAlpine 1990).

the Late Jurassic and Early Cretaceous resulted in a peneplain known as the Avalon Unconformity (Grant et al., 1986). Slow regional subsidence followed during which Late Cretaceous and Tertiary deep-water mudstone and shales were deposited (McAlpine, 1990).

2.1.2. Geology of the Jeanne d'Arc Basin: Post-Cenomanian

This thesis involves modeling a canyon system and surrounding formations of Late Cretaceous to Early Tertiary age and thus this interval is discussed in greater detail here. The stratigraphy of the Jeanne d'Arc Basin during post-Cenomanian time (Fig. 2.2 and 2.3) reflects changes in eustatic sea level (de Silva, 1993).

A transgressive systems tract formed during the Cenomanian due to a rise in eustatic sea level and inundation of the basin's margins (de Silva, 1993). Shale, marlstone, and siltstone were the dominant lithologies deposited in the basin (de Silva, 1993). A maximum flooding surface resulted in the deposition of chalk and marlstone to form the Turonian aged Petrel Member (de Silva, 1993) (Fig. 2.3 and 2.4).

This transgressive phase was followed by a highstand system during which eustatic sea level was at a standstill (Fig. 2.3). Sediments from the western margin of the basin prograded onto the shelf due to a lack of accommodation space, forming the deltaic Otter Bay Member

Stratigraphic Units	Systems Tracts
Middle Eocene unconformity	*Sequence Boundary*
Unnamed shaly unit	Transgressive Systems Tract/ Highstand Systems Tract
South Mara unit	Lowstand Systems Tract
Base Tertiary unconformity	*Sequence Boundary*
Otter Bay unit	Highstand Systems Tract
Petrel Member	
Eider sand / Nautilus Shale formations	Transgressive Systems Tract
Albian/Cenomanian unconformity	*Sequence Boundary*

Figure 2.2 Depositional framework of the Late Cretaceous-Paleozoic rock units in the southern part of the Jeanne d'Arc Basin (Agrawal et al., 1995)..

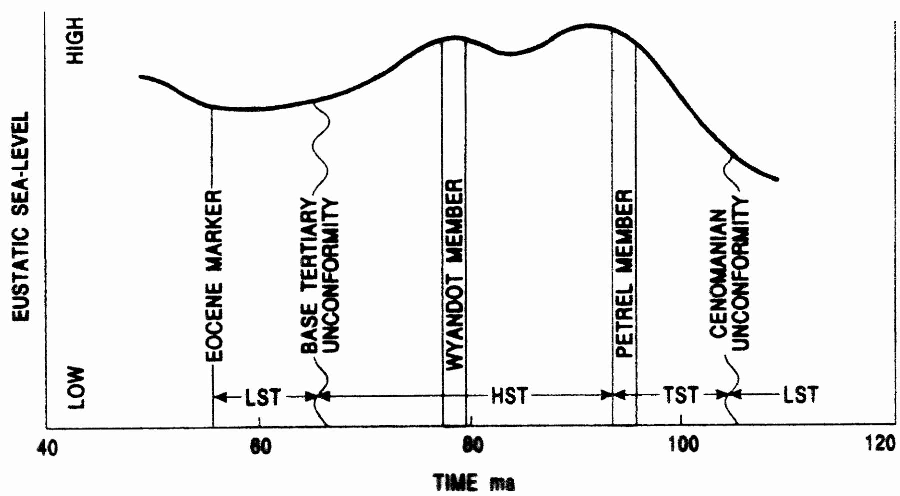


Figure 2.3 Eustatic sea-level curve, seismic markers, and depositional systems (from de Silva 1993).

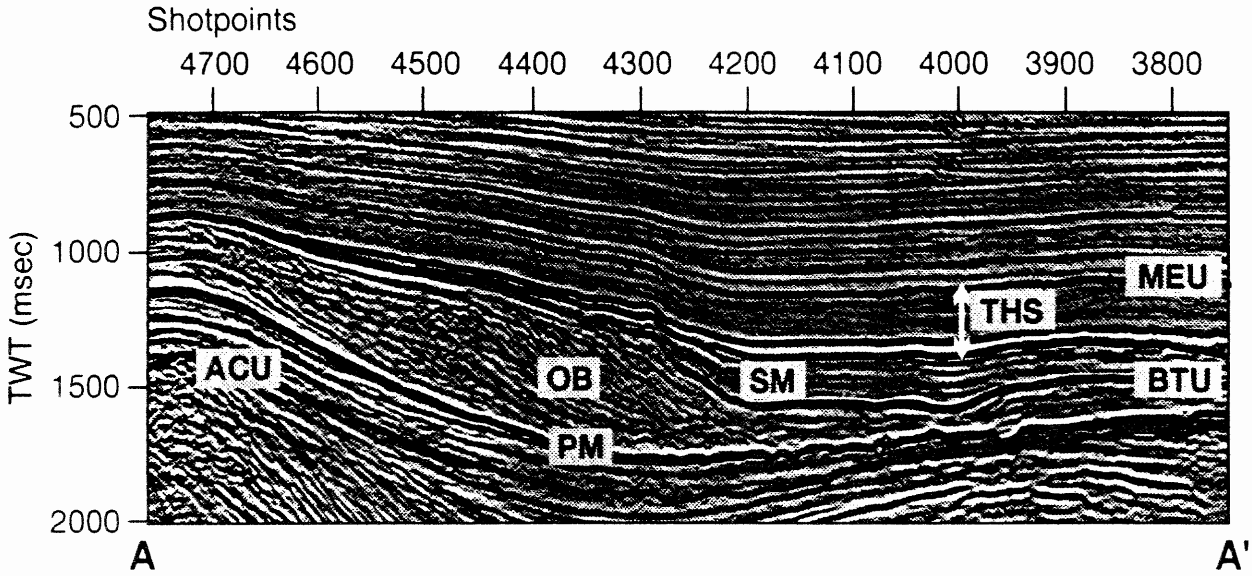


Figure 2.4 West-east seismic profile showing general stratigraphic section, and unconformities. ACU, Albian/Cenomanian unconformity; BTU, Base Tertiary unconformity; MEU, Middle Eocene unconformity; PM, Petrel Member top; OB, Otter Bay unit; SM, South Mara unit; THS, transgressive/highstand units (from Agraval et al. 1995).

sandstones (de Silva, 1993) (Fig. 2.4). Eustatic sea level rose to form another major flooding surface during which chalk and marlstone of the Wyandot Member were deposited (de Silva, 1993). A second deltaic sandstone, the Fox Harbour Member, formed as sediments prograded again towards the east (de Silva, 1993). Submarine fans were deposited at the base of the shelf slope as sea level and accommodation space continued to decrease (de Silva, 1993).

A further decrease in sea level resulted in a lowstand systems tract (de Silva, 1993). The shelf was subaerially exposed and eroded resulting in the Base Tertiary Unconformity (Fig. 2.4). At least four canyon systems eroded into the Fox Harbour and Otter Bay units (Agrawal et al., 1995). One of these canyons is the Hibernia Paleocene Canyon, which is the focus of this thesis. These canyon systems carried sand-rich sediments eroded from the deltaic sandstones of the shelf to the basin floor forming lowstand fans (de Silva, 1993) (Fig. 1.1). A lowstand wedge formed on the shelf and slope in areas outside of the canyons and fans; its lithology is dominantly siltstone and shale (de Silva, 1993). Rapid sea level rise followed terminating the lowstand system tract and depositing mudstone and shale of the Banquereau Formation.

2.2 Submarine Canyons

Submarine canyons are narrow V- and U- shaped valleys that have deeply eroded into the continental shelf and slope (Shepard and Marshall, 1978). Submarine canyons may form over a long period of time as a result of several stages of erosion due to a combination of mechanisms (Shepard, 1981). These include subaerial erosion, turbidity currents, retrogressive slope failure, debris flows, and fault valleys (Pratson et al., 1994; Shepard, 1981).

Subaerial erosion results as rivers erode onto the continental shelf during periods of low sea level to form canyons that are later submerged by sea level rise. Heads of submarine canyons are frequently found at the mouth of rivers. For example, submarine canyons on the west coast of Corsica and along the Hawaiian coast appear to be a continuation of land canyons (Shepard, 1981). River erosion, however, cannot explain a vast number of submarine canyons that lie seaward of the continental shelf or that reach depths too deep for subaerial exposure (Pratson, 1994). Furthermore, features in modern day submarine canyons appear to be largely due to marine erosion (Shepard, 1981).

Turbidity currents, due to their high erosive power, are considered to be one of the most important factors in the formation of submarine canyons or in the modification of submarine canyons formed by other processes (Shepard, 1981). Retrogressive slope failure results in up canyon erosion which can also explain the initiation of submarine canyons that lie far from the shelf edge (Pratson et al., 1994). Dives in submarine canyons off the coast of New England indicate that debris flows have moved large boulders great distances down canyon (Ryan et al., 1978 in Shepard, 1981) and thus debris flows are also an important contributor to submarine canyon formation. Some submarine canyons appear to have been initiated by submarine fault valleys and were later eroded by marine processes. For example, submarine canyons off the coast of Baja California appear to follow faults (Normark and Curray, 1968 in Shepard, 1981).

The morphology of the Hibernia Paleocene Canyon may indicate what geological processes initiated and further altered the canyon (Shimeld et al., in prep.). For example, evidence of scouring and slumping on walls of the canyon, variation in seismic facies within the canyon fill indicative of several erosive and infilling events, changes in hydrodynamic regimes, and the presence of down canyon links to basin-floor fans are observed (Shimeld et al., in prep.).

2.3 Compaction

Sediments are subjected to pure strain by the weight of overlying sediments resulting in a reduction of porosity and hence formation thickness with time (Leeder, 1980). The magnitude of compaction reflects grain size; fine grained sediments containing organic matter and clay minerals compact the most while coarse grained sediments compact the least (Leeder, 1980).

Sandstone porosity reduction with depth is approximately linear (Magara, 1980).

Conversely, porosity reduction in shales approximates an exponential relationship (Magara, 1980). At shallow depths the platy grains within the shale are misaligned and the contact area between grains is therefore small. At greater depth, grains are aligned and the contact area between grains is larger. Thus, if pressure increase is constant, the applied pressure per unit contact area at shallow depth is larger then that at greater depth (Magara, 1980). Shale at shallow depth will, therefore, undergo more rapid porosity reduction than shale at greater depth.

Many different curves have been proposed that describe the compaction of clastic sediments with depth: Athy (1980), Baldwin (1971), Dickinson (1953), Durmish'yan (1974), Hunt (1979), Magara (1976), Maxwell (1964), Pryor (1973), Sclater andChristie (1980), etc. as seen in Figures 2.5 and 2.6. The compaction curve used in modeling the canyon system is the Sclater and Christie (1980) curve. It was derived from a study of eight wells on the flanks of and in the middle of the Central Graben of the North Sea. The equation relates the present day porosity to the initial porosity and depth as follows:

$$P = P_0 e^{-cz}$$

where P = porosity
P_0 = initial porosity
c = compaction factor
z = depth in km

This compaction equation accounts for different lithologies by a lithology-dependent constant, c,

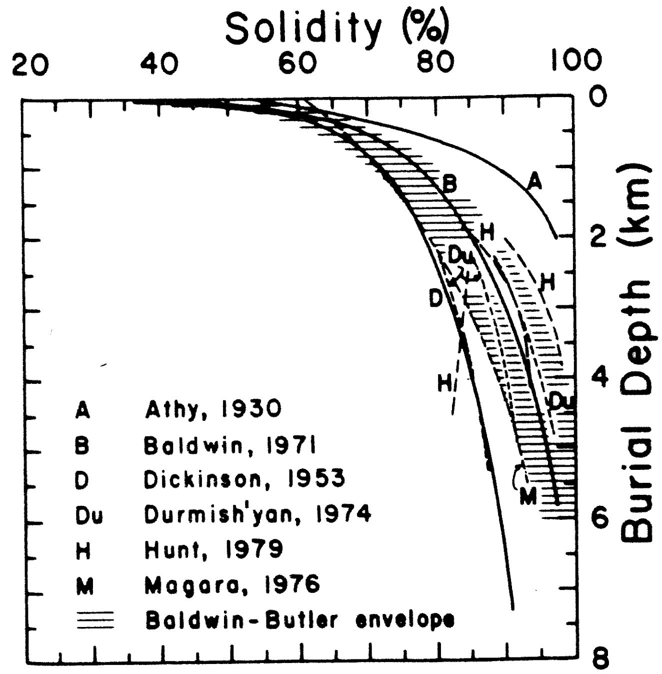


Figure 2.5 Selected compaction curves for argillaceous sediments (from Baldwin and Butler 1985). Burial depth is plotted against solidity. Solidity is defined as the volume of solid grains as a percent of total volume of sediment.

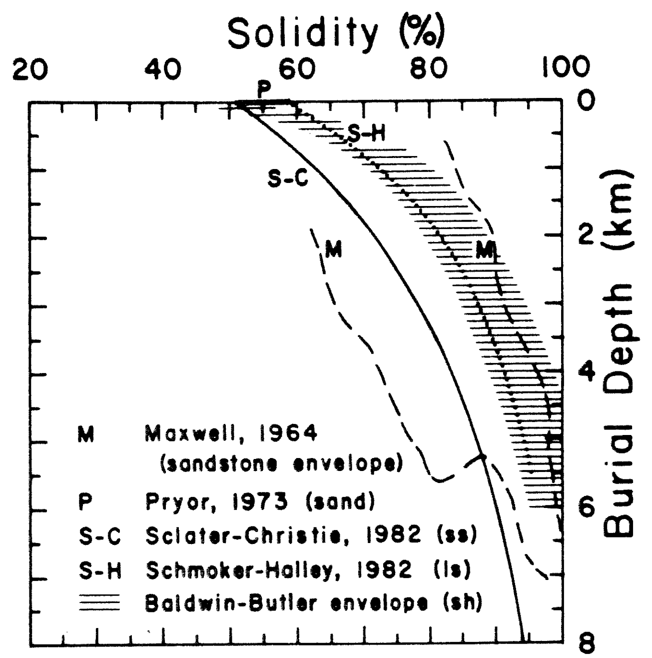


Figure 2.6 Compaction curves for sandstone, limestone, and shale (from Baldwin and Butler 1985). Burial depth is plotted against solidity. Solidity is defined as the volume of solid grains as a percent of total volume of sediment.

where c is 0.27 km^{-1}, 0.41 km^{-1}, 0.51 km^{-1}, and 0.22 km^{-1} for sandstone, siltstone, shale, and limestone, respectively.

CHAPTER THREE: MODELING PROCEDURE

3.1. Geological Inputs to Model

Geological information for the model was obtained from the Hibernia J-34 well which is located approximately 3 km from the Hibernia Paleocene Canyon, as seen in Figure 1.1. Tops of known age were entered into BasinMod 1D. Ages are based on lithostratigraphic picks (CNOPB, 1990) and biostratigraphic picks from foraminifera data (Thomas, 1994) and palynological data (Williams, pers. comm.; Williams et al., 1990). Table 3.1 lists the depth, age, and source of the lithostratigraphic and biostratigraphic picks used in the model.

The model includes rock to a depth of 1870 m. As there are no cores within this interval, lithologies are based on the cuttings description in the Mobil et al. Hibernia J-34 Well History Report. Cuttings were taken at a 10 m interval from 440 m to 1000 m and at a 5 m interval from 1005 m to 2455 m. Table 3.2 lists the begin age, well top, present thickness, and lithological breakdown for each of the events defined by the well tops. Events bearing the name Biostrat indicate intervals for which a biostratigraphic age is available; intervening events contain the name Unit. Age dates for the latter were linearly interpolated.

Estimated values for initial porosity, density, grain size, and other parameters for the

Depth Interval (m)	Age (Ma)	Source
430-440	Late Miocene	Thomas, 1994
470-640	Early and Middle Miocene	Thomas, 1994
670-680	Oligocene	Thomas, 1994
790-1085	Middle and Late Eocene	Thomas, 1994
1115-1230	Lutetian	Williams, pers. comm.
1230-1240	Thanetian	Williams, pers. comm.
1270-1280	Danian	Williams, pers. comm.
1286-1360	Maastrichtian	CNOPB, 1990
1482-1622	Coniacian	CNOPB, 1990
1716-1819	Turonian	CNOPB, 1990
1870-1990	Cenomanian	Williams et al., 1990

Table 3.1 Biostratigraphic and lithostratigraphic picks for Hibernia J-34.

Event Name	Begin Age (Ma)	Well Top (m)	Present Thickness (m)	% Sandstone	% Siltstone	% Shale	% Limestone
Unit1	8.2	0	323	20	10	70	0
Unit2	10.9	323	107	20	10	70	0
Biostrat3	11.2	430	10	85	0	15	0
Unit4	13.1	440	30	85	0	15	0
Biostrat5	23.7	470	170	5	20	75	0
Unit6	33.4	640	30	15	0	85	0
Biostrat7	36.6	670	10	15	20	65	0
Unit8	38.1	680	110	0	0	80	20
Biostrat9	42.0	790	295	0	9	75	16
Unit10	43.4	1085	30	0	0	100	0
Biostrat11	49.0	1115	115	0	0	94	6
Biostrat12	56.0	1230	10	0	10	90	0
Fox Harbour Member	74.5	1286	74	85	0	15	0
Unit14	81.0	1360	122	31	20	45	4
Otter Bay Member	88.5	1482	140	100	0	0	0
Unit16	89.7	1622	94	42	0	58	0
Petrel Member	91.0	1716	103	0	21	24	55
Unit18	92.9	1819	51	10	70	10	10

Table 3.2 Begin age, well top, present thickness, and lithology of Hibernia J-34 (Mobil et al., 1982; Thomas, 1994; Williams, pers. comm.; CNOPB, 1990; Williams et al., 1990).

dominant lithologies in the model are listed in Table 3.3. These are the default values given by BasinMod 1D; they can be edited to fit well information. As geological information was restricted to cuttings descriptions, the values in Table 3.3 are considered to be the best approximations. These values were later varied to consider the sensitivity of the model to the lithological parameters.

3.2 One Dimensional Modeling Procedure

The modeling procedure used for BasinMod 1D is shown diagrammatically in Figure 3.1. Two dummy wells were created; the first well, Well A, lies just outside the canyon, while the second well, Well B, penetrates the canyon fill of varying lithology. Lithologies and ages of the wells are based on Hibernia J-34 data as described above. Well tops from Hibernia J-34 were picked across the seismic section seen in Figure 3.2. This cross section is from a 3D seismic reflection survey with bin spacings of 12.5 m that was shot in 1990 by the Hibernia Management and Development Company. The location of the cross section is shown in Figure 1.1. Lithological values and ages from Hibernia J-34 are considered to be constant between well tops across the section. Figure 3.3 is a depth converted cross section showing the location of the two dummy wells. The depth cross section was created from interval velocities (Table 3.4) which were calculated from time-depth pairs from Hibernia J-34 by the following equation:

	SANDSTONE	SILTSTONE	SHALE	LIMESTONE
Initial Porosity (Fraction)	0.45	0.55	0.60	0.60
Exponential Compaction Factor (1/km)	0.27	0.41	0.51	0.22
Density (g/cm^3)	2.64	2.64	2.60	2.72
Grain Size (mm)	0.5	0.0156	0.0004	0.5

Table 3.3 Lithological parameters for dominant lithologies in model given by BasinMod. The initial porosity is the porosity of the sediments at the time of deposition. The exponential compactor factor is an indication of how much a formation will compact and is used in the Sclater and Christie (1980) equation. Values are between 0.0 km^{-1} and 2.0 km^{-1}, where 0.0 km^{-1} describes a formation that does not compact. The density and grain size are the mean matrix density and average grain size of the deposit, respectively.

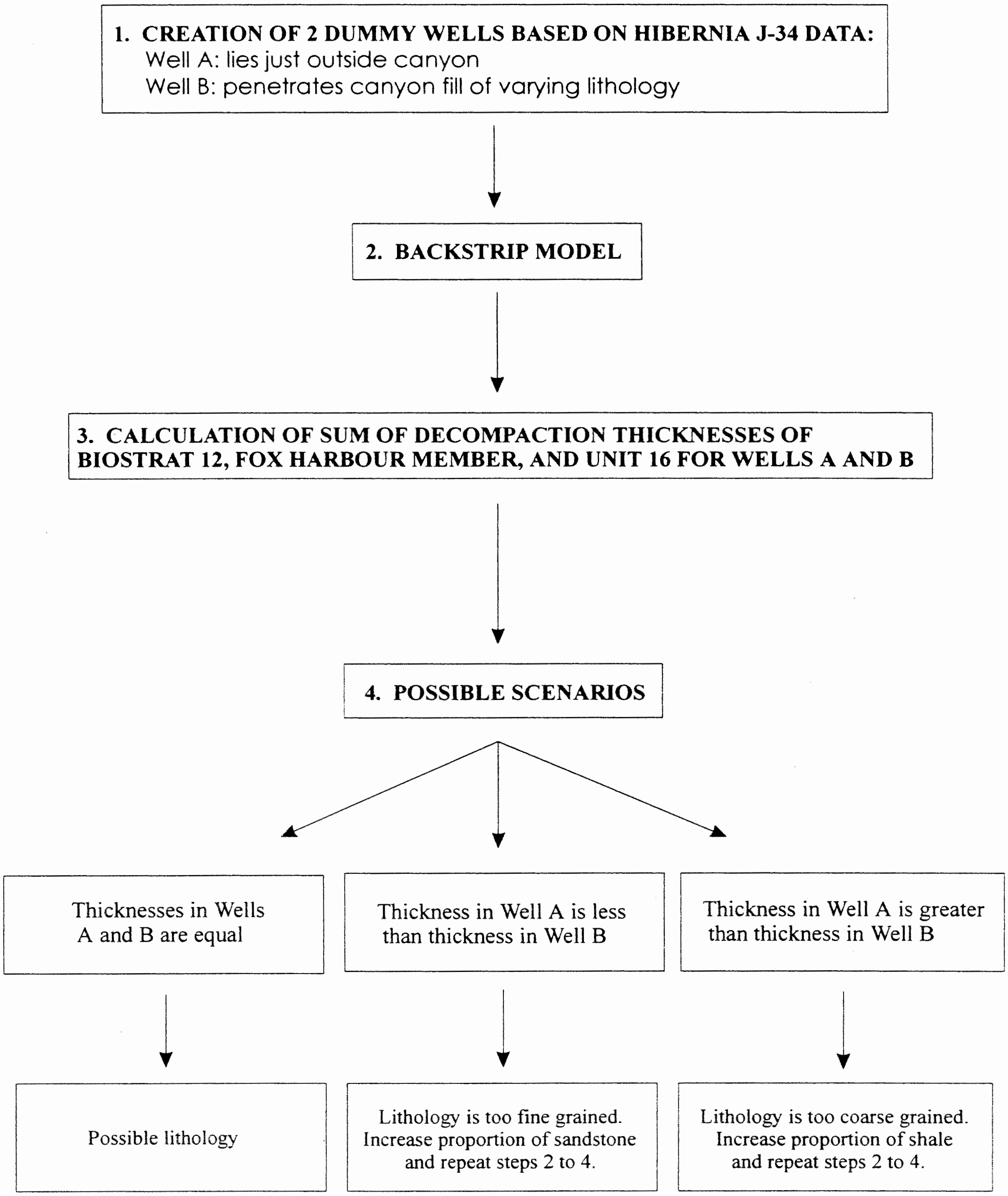


Figure 3.1 One dimensional modeling procedure.

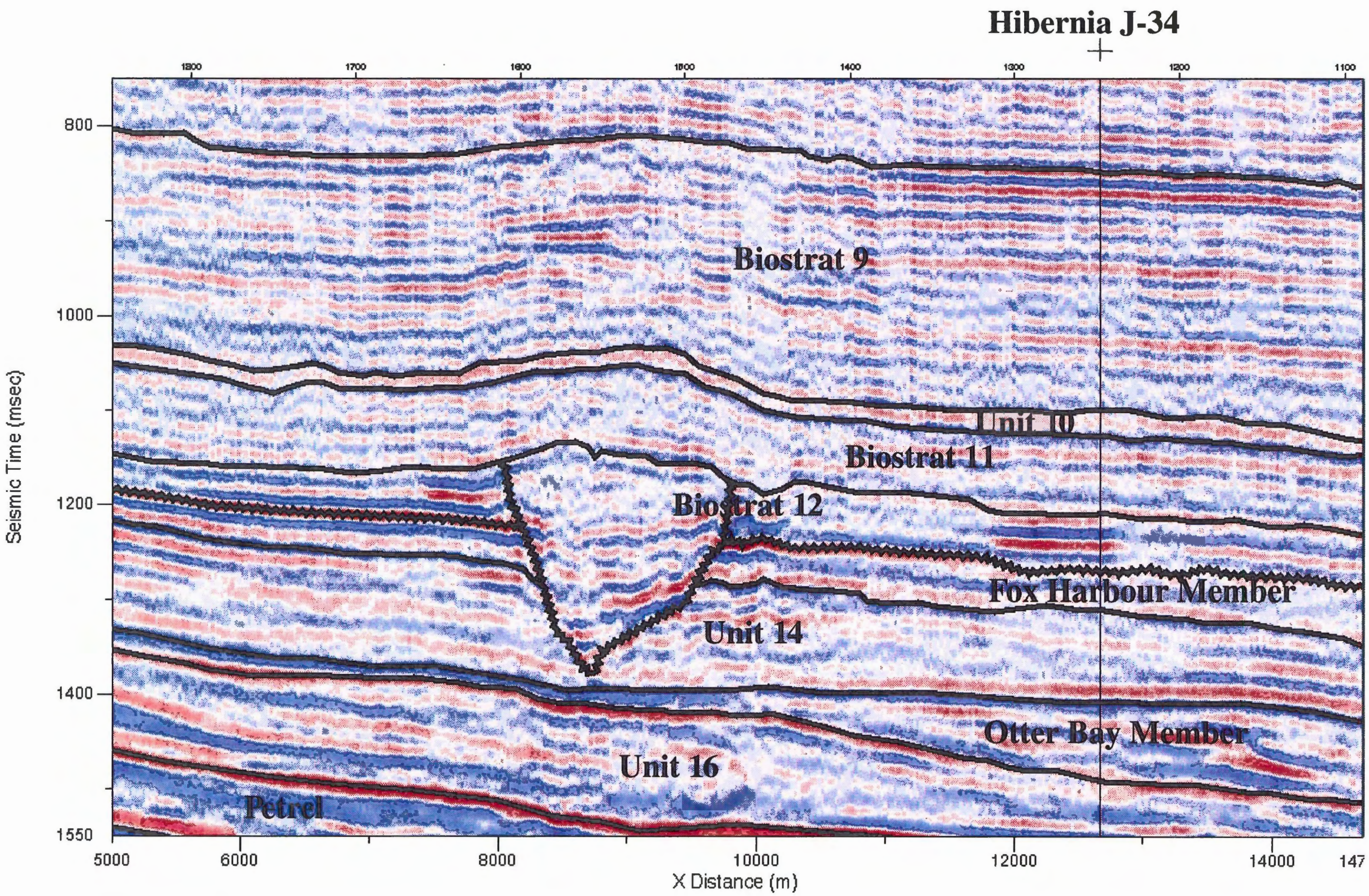


Figure 3.2 Cross section in time showing the Hibernia Paleocene Canyon and Base Tertiary Unconformity (jagged lines) and all other horizons used in model. Refer to Table 3.3 for lithologies of events. Location of cross secton is shown in Figure 1.1.

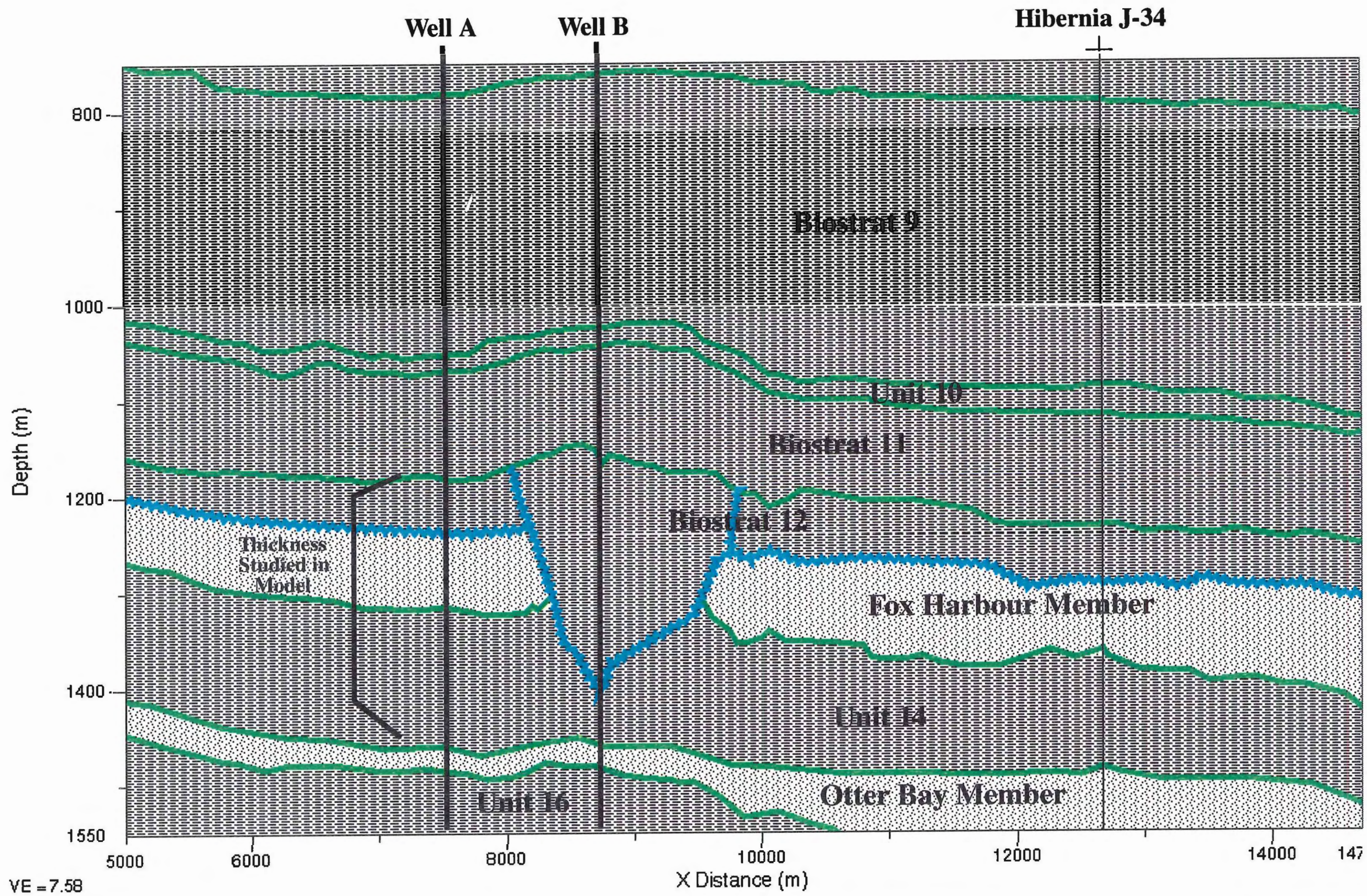


Figure 3.3 Cross section in depth showing location of Well A and Well B. The Hibernia Paleocene Canyon and the Base Tertiary Unconformity are shown in blue (jagged line) and all other horizons are in green. Event names are given in black. Refer to Table 3.3 for lithologies of events. Dashed events are shale-dominanted, while stippled events are sandstone-dominanted. Location of cross section is shown in Figure 1.1.

Event Name	Interval Velocity (m/s)
Unit1	1920
Unit2	1860
Biostrat3	2000
Unit4	2400
Biostrat5	1890
Unit6	1760
Biostrat7	2300
Unit8	1750
Biostrat9	2340
Unit10	2220
Biostrat11	2420
Biostrat12	1800
Unit13	2610
Biostrat14	2290
Fox Harbour Member	3700
Unit16	2500
Otter Bay Member	3350
Unit18	2650
Petrel	3500

Table 3.4 Interval velocities for events in cross section.

interval velocity = d_2 - d_1 / t_2 - t_1,

where d is depth and t is time

The combined thickness of Biostrat 12, the Fox Harbour Member, and Unit 14 (Fig. 3.3) in Well A and Well B is considered to have been equal 49 Ma before present, i.e. the end age of deposition of Biostrat 12. This results from the assumption that the top of Biostrat 12 was flat upon deposition and the fact that the base of Unit 14 is found at the same depth in both wells.

Wells A and B were backstripped to remove the effect of compaction with time. The sum of the decompacted thicknesses of Biostrat 12, the Fox Harbour Member, and Unit 14 were determined and compared for Wells A and B at a time slice of 49 Ma. There are three possible relationships between the decompacted thicknesses of the two wells (Fig. 3.1). If the top of Biostrat 12 were flat upon deposition, then the sum of the decompacted thicknesses should be approximately equal for Well A and Well B. A substituted canyon fill lithology in Well B that results in the same decompacted thickness as Well A indicates a possible canyon fill lithology. A second possible outcome is if the sum of the decompacted thicknesses in Well A is greater than that in Well B. This would suggest that the canyon fill has not undergone enough decompaction and the substituted fill is too sandstone-rich. The final possible outcome is if the sum of the decompacted thicknesses in Well A is less than that in Well B. In such a case, the substituted canyon fill must have undergone too much decompaction and is too shale-rich. The canyon fill lithology can be varied until equal decompacted thicknesses in Wells A and B are achieved.

This test assumes that the positive relief observed in sediments directly overlying the canyon is due to normal compaction alone. If no substituted lithology results in equal decompacted thicknesses, then normal compaction of the canyon fill and surrounding sediments cannot account for the observed positive relief over the canyon.

3.3 Two Dimensional Modeling Procedure

Modeling of the Hibernia Paleocene Canyon was extended to two dimensions using BasinMod 2D in an effort to observe the effect of decompaction over the entire width of the canyon. Using two different software packages also helps to confirm the validity of the results. The depth converted cross-section seen in Figure 3.3 forms the basis of the two dimensional model. Well tops from Hibernia J-34 were picked across the section. Geological information described in Section 3.1 was imported from BasinMod 1D to BasinMod 2D and fitted to the observed structures on the cross section; lithologies and ages between well tops are considered to be constant across the section.

The procedure followed for BasinMod 2D is similar to that of BasinMod 1D. Several cross sections were created in which the canyon fill lithology was varied. The cross section was backstripped; any time slice of the canyon system can be obtained and thus the effect of compaction over time can be observed.

The top of Biostrat 12 is assumed to have been flat at 49 Ma, i.e. the time of its deposition. Furthermore, the top of the Otter Bay Member is considered to have been approximately flat between the canyon and the location of Well A at 49 Ma. In backstripping the model to 49 Ma, BasinMod 2D will force the top of Biostrat 12 to be flat. Thus, a flat Otter Bay Member top between the canyon and Well A on a time slice at 49 Ma is indicative of equal decompacted thicknesses of Biostrat 12, the Fox Harbour Member, and Unit 14. Equal decompacted thicknesses suggest that the substituted lithology is a possible canyon fill lithology. Thus, a time slice at 49 Ma for a certain canyon fill lithology showing a flat Otter Bay Member top suggests that the substituted lithology is a possible canyon fill lithology. An Otter Bay Member high under the canyon suggests that the canyon fill has not undergone enough decompaction, i.e. the substituted lithology is too sandstone-rich. Conversely, if the top of the Otter Bay Member is a low under the canyon, then the canyon fill has undergone too much decompaction and the substituted lithology is too shale-rich. The lithology of the canyon fill can be varied until the decompacted model at 49 Ma shows a flat Otter Bay Member top between the location of the canyon and Well A. As in the case of the one dimensional modeling procedure, if no lithology fits this criterion, differential compaction of the canyon fill and surrounding sediments alone cannot account for the observed positive relief.

3.4 Variation of Canyon Fill Lithology in Model

Sandstone and shale are considered as likely canyon fill end member lithologies in the model. Adjacent strata and much of the stratigraphic succession of similar age in the Jeanne d'Arc Basin are dominantly sandstone and shale. Furthermore, most modern canyons have a detrital fill of this kind.

Parameters for any given lithology can be varied. The default values are given in Table 3.3. The initial porosity and the exponential compaction factor greatly affect the amount of compaction and therefore lithologies with a range of values need to be considered. The canyon fill may be a homogeneous mixture or consist of interbedded shale and sandstone. Thus, there are a number of possible canyon fill lithologies; the modeling cannot provide a detailed succession but can help to constrain the proportion of sediment types in the fill..

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 One Dimensional Modeling Results

The thickness of Biostrat 12, the Fox Harbour Member, and Unit 14 versus time is shown in Figures 4.1, 4.2, and 4.3 for Well A, situated outside canyon, Well B_1, containing a pure sandstone canyon fill, and Well B_2, containing a 90% shale and 10% siltstone canyon fill, respectively. The lithology of the canyon fill in Well B_2 is the same as that of Biostrat 12 in Hibernia J-34. These plots show that thickness increases from 0 m to a maximum value at the end of deposition of the unit. From the end of deposition to the present day, the units decrease in thickness due to dewatering and compaction of sediments. Note the greater initial rate of compaction for the shale canyon fill versus the sandstone canyon fill (Fig. 4.2 and 4.3).

The decompacted thicknesses of Biostrat 12, the Fox Harbour Member, and Unit 14, and the sum of these thicknesses are listed in Table 4.1. The lithologies used have the default lithological parameters given in Table 3.3. A pure sandstone canyon fill results in a total decompacted thickness that is thinner than that of the surrounding formations, i.e. Well B_1 and Well A have decompacted thicknesses of 354 m and 383 m, respectively. Conversely, a shale canyon fill decompacts to a thickness of 437 m which is 54 m greater than the decompacted thickness of Well A. The decompacted thickness of the pure sandstone fill is a closer

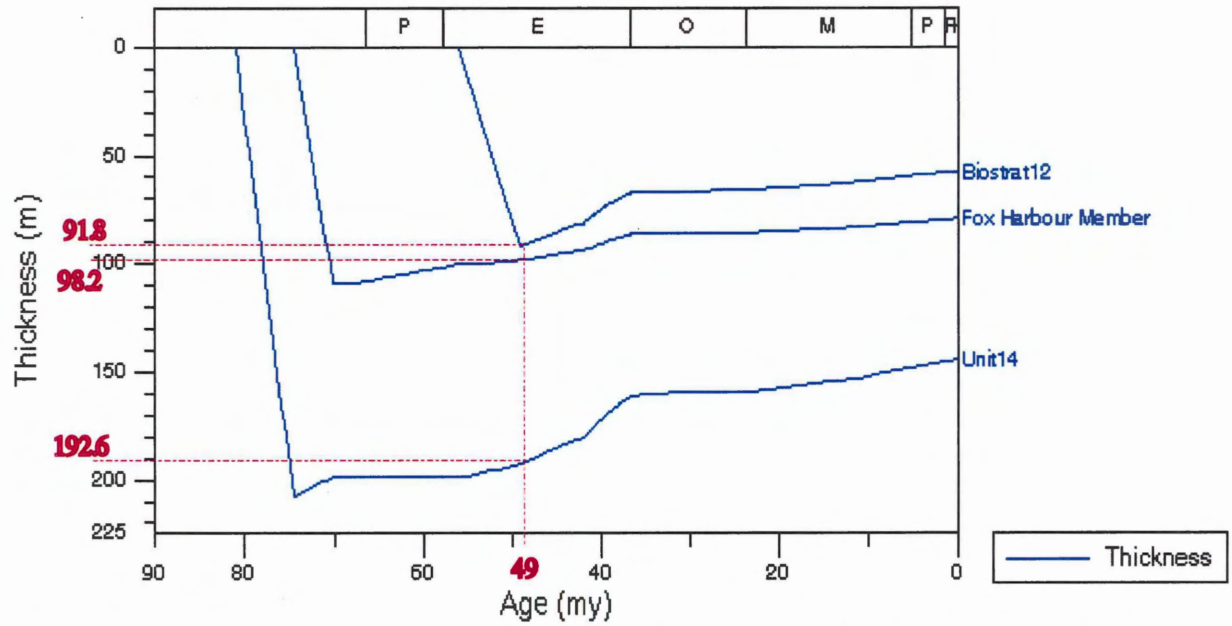


Figure 4.1 Plot of thickness versus time for well outside canyon (Well A). Dashed lines indicate the decompacted thickness of events 49 Ma before present. From left to right, the letters at the top of the graph represent Paleocene (P), Eocene (E), Oligocene (O), Miocene (M), Pliocene (P), and Pleistocene (A).

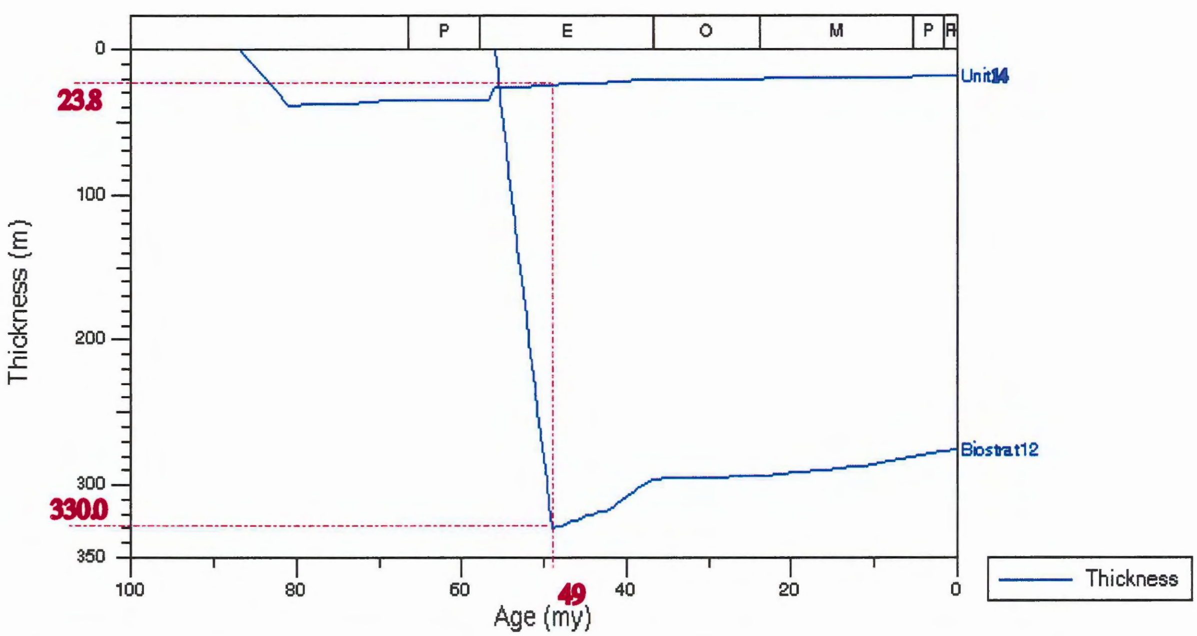


Figure 4.2 Plot of thickness versus time for well inside canyon with 100% sandstone fill (Well B_1). Dashed lines indicate the decompacted thickness of events 49 Ma before present.

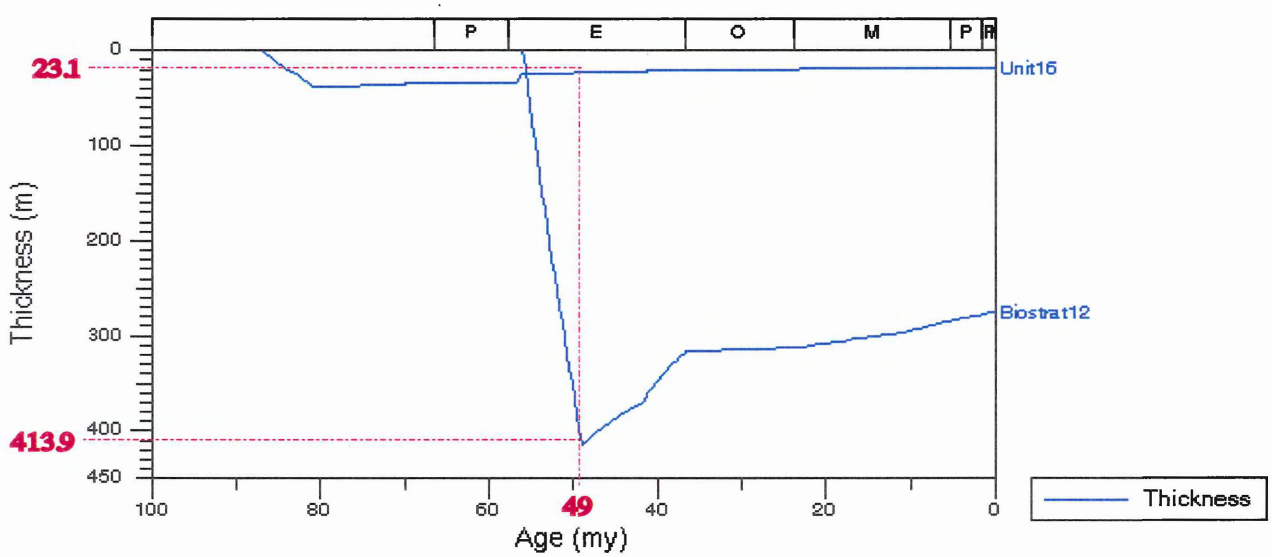


Figure 4.3 Plot of thickness versus time for well inside canyon with 90% shale and 10% siltstone fill (Well B_2). Dashed lines indicate the decompacted thickness of events 49 Ma before present.

	Well A	**Well B_1**	**Well B_2**	**Well B_3**	**Well B_4**
Biostrat 12 (m)	91.9	330.0	413.9	360.7	355.8
Fox Harbour Member (m)	98.2	0.0	0.0	0.0	0.0
Unit 14 (m)	192.6	23.8	23.1	23.6	23.6
Total Decompacted Thickness (m)	**382.7**	353.8	437.0	**384.3**	**379.4**

Table 4.1 Comparison of the decompacted thicknesses in metres of Biostrat 12, the Fox Harbour Member, and Unit 14 for Wells A and Well B of varying lithology. The canyon fill lithologies for Well B are as follows: Well B_1 = 100% sandstone, Well B_2 = 90% shale and 10% siltstone (lithology of Biostrat 12 in Hibernia J-34), Well B_3 = mixture of 65% sandstone and 35% shale, and Well B_4 = 165 m of sandstone overlying 110 m of shale. Total decompacted thicknesses in bold compare well. The default lithological parameters as listed in Table 3.3 were used.

approximation to that of the surrounding formations and thus the canyon fill likely contains more sandstone than shale.

Wells B_3 and B_4 were constructed to observe the effect of decompaction on canyon fill intermediate between sandstone and shale. The canyon fill in Well B_3 is composed of a homogeneous mixture of 65% sandstone and 35% shale. Well A and Well B_3 have decompacted thicknesses of 383 m and 384 m, respectively (Table 4.1). This suggests that a canyon fill with these proportions of sandstone and shale is a possible lithology. Alternatively, the canyon fill may be inhomogeneous and consist of layers of sandstone and shale. For example, Well B_4 has 165 m of sandstone overlying 110 m of shale within the canyon. The decompacted thickness of Well B_4 , 379 m, closely approximates that of Well A, 383 m (Table 4.1).

4.2 Two Dimensional Modeling Results

The first two models created in BasinMod 2D vary the canyon fill lithology between 100% sandstone and 90% shale/ 10% siltstone (lithology of Biostrat 12 in Hibernia J-34) as seen in Figures 4.4(a) and 4.4(b), respectively. These models were backstripped to remove the effect of compaction; a time slice at 49 Ma is shown for each model in Figure 4.5(a) and 4.5(b).

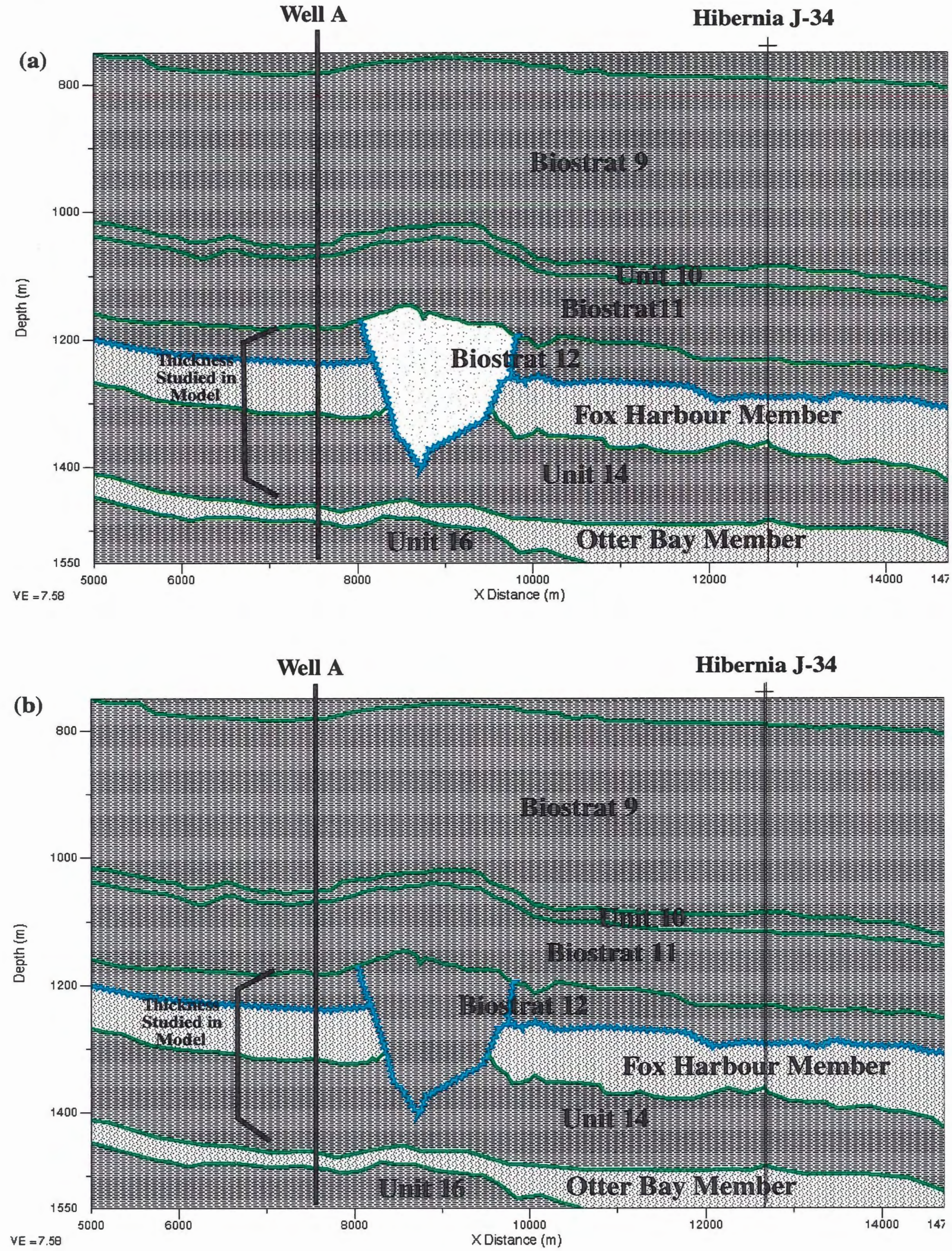


Figure 4.4 Cross section in depth at 0 Ma with (a) sandstone canyon fill and (b) 90% shale and 10% siltstone canyon fill. The Hibernia Paleocene Canyon and the Base Tertiary Unconformity are shown in blue (jagged line) and all other horizons are in green. Event names are in black. Dashed events are shale-dominanted, while stippled events are sandstone-dominanted. Location of cross-section shown in Figure 1.1.

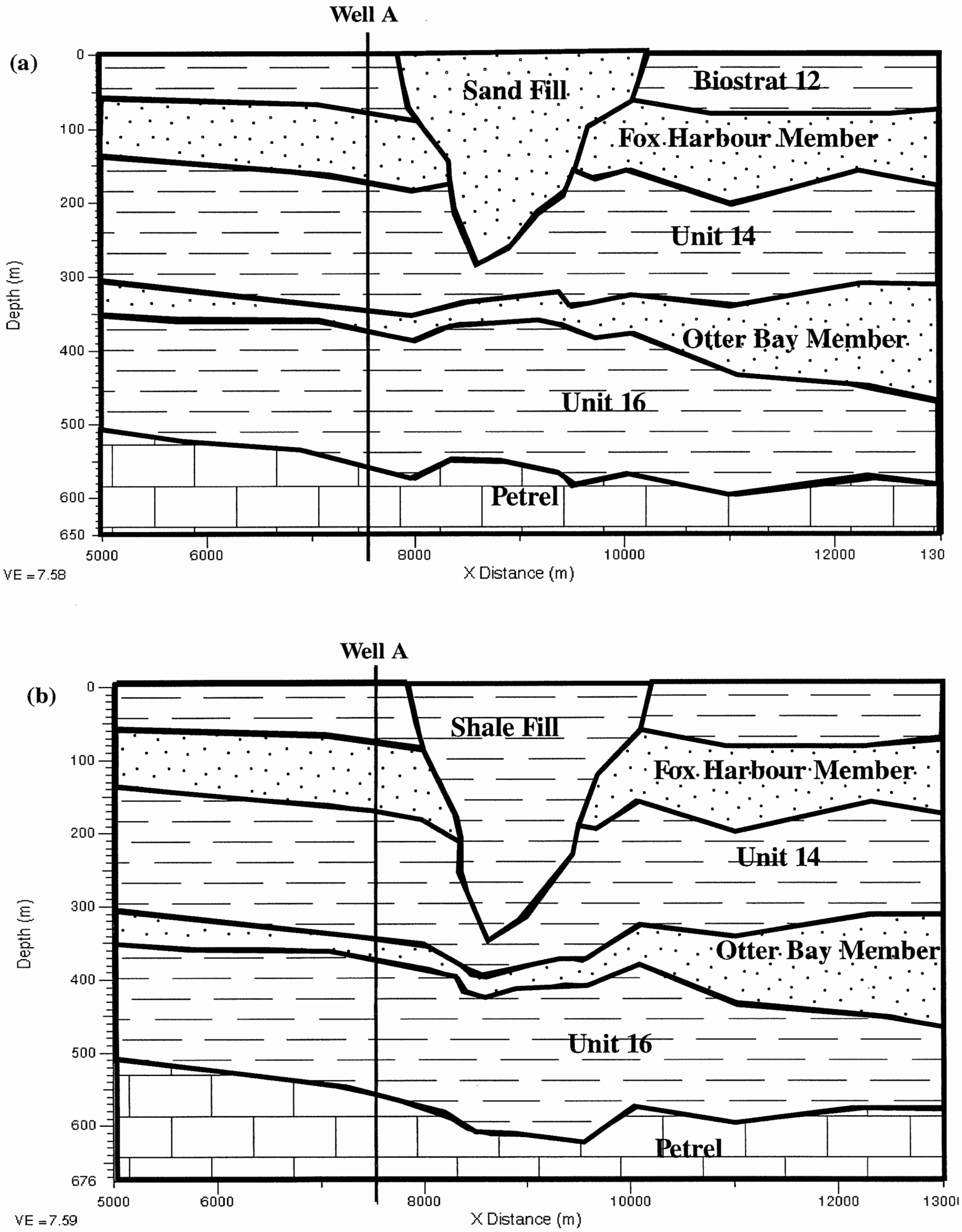
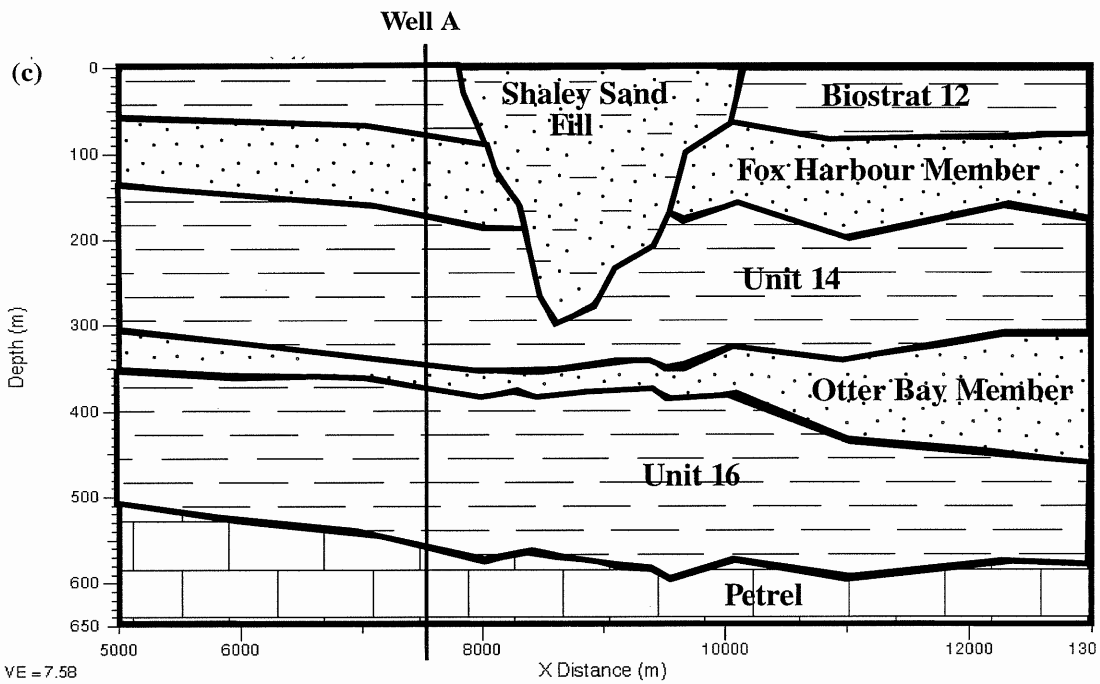


Figure 4.5 Time slice at 49 Ma for 2D model. (a) Canyon fill is pure sandstone. (b) Canyon fill is 90% shale and 10% siltstone, i.e. the lithology of Biostrat 12 in Hibernia J-34. (c) (Next page.) Canyon fill is 60% sandstone and 40% shale. Shale-rich units are dashed, sandstone-rich units are stippled, and limestone-rich units are shown by the rectangular pattern.


Well A
(c)
Shaley Sand Fill
Biostrat 12
Fox Harbour Member
Unit 14
Otter Bay Member
Unit 16
Petrel
Depth (m)
0
100
200
300
400
500
600
650
5000
6000
8000
10000
12000
130
X Distance (m)
VE =7.58

Events become progressively thicker from the present day cross section to the 49 Ma time slice. Overlying layers have been removed allowing sediments to decompact because they have risen to a shallower depth. Increases in the thickness of shale units are greater than sandstone units as the latter undergo less compaction. The shale-siltstone canyon fill is significantly thicker than the sandstone canyon fill (Fig. 4.5(a) and 4.5(b)).

As discussed in Section 3.3, a possible canyon fill lithology is a lithology that results in an equal sum of decompacted thicknesses of Biostrat 12, the Fox Harbour Member, and Unit 14 between the canyon and Well A at 49 Ma. The Otter Bay Member in the model of a pure sandstone canyon fill is elevated beneath the canyon relative to the location of Well A (Fig. 4.5(a)). This elevation reflects a decompacted thickness that is less than that at the location of Well A, suggesting that a pure sandstone canyon fill does not undergo enough decompaction. In contrast, the Otter Bay Member is a low in the model of a pure shale canyon fill (Fig. 4.5(b)). A pure shale canyon fill undergoes too much decompaction resulting in a thick canyon fill at 49 Ma that deflects the top of the Otter Bay Member downward.

The canyon fill lithology is likely intermediate between sandstone and shale because pure sandstone fill results in too little decompaction and a dominantly shale fill results in too much decompaction. Several more models were created in which the proportion of the sandstone and shale were varied. Figure 4.5(c) shows the 49 Ma time slice of a model with 60% sandstone and

40% shale. The Otter Bay Member is approximately flat between the canyon and the location of Well A. This sandstone-shale proportion results in the flattest Otter Bay Member top of the models created and thus the canyon fill is likely composed of a mixture of 60% sandstone and 40% shale.

4.3 Sensitivity of Model Parameters

The geological information used in the model is restricted to cuttings descriptions from well in strata adjacent to canyon fill and thus, there is uncertainty in the initial porosity, exponential compaction factor, and grain size of all lithologies. The lithological parameters used in the modeling as listed in Table 3.3 are considered to be good approximations. Variations in these values are considered here.

The canyon fill may be composed of a sandstone with a larger initial porosity or a greater exponential compaction factor than those assumed by the default values in Well B_1. Increasing these values results in greater decompaction. The effect of varying these parameters for Well B_1 is shown in Table 4.2. Increasing the initial porosity of sandstone from 0.45 to 0.48 and increasing the exponential compaction factor from 0.27 to 0.35 will result in a decompacted thickness of 373 m, which is 19 m greater than the model with default lithological values but 10 m less than that of Well A. Higher values may not be representative of a sandstone. Thus, a pure

LITHOLOGICAL PARAMETERS	DECOMPACTED THICKNESS (m) OF BIOSTRAT 12, FOX HARBOUR MEMBER, AND UNIT 14 FOR WELL B_1
Default values	353.8
Increase Porosity of Sandstone From 0.45 to 0.48	360.3
Increase Exponential Compaction Factor From 0.27 to 0.35	365.0
Decrease Initial Grain Size From 0.50 mm to 0.10 mm	no change
Combination of Above Listed Changes	372.7

Table 4.2 Changes in decompacted thickness in Well B_1 (pure sandstone fill) with changes in initial porosity, exponential compaction factor, and grain size.

sandstone canyon fill cannot account for the positive relief observed over the canyon, regardless of the sandstone parameters used. However, increasing the initial porosity and exponential compaction factor of sandstone results in a greater proportion of sandstone within the canyon fill.

Conversely, if the initial porosity and exponential compaction factor of a sandstone canyon fill are decreased, then the canyon fill undergoes less compaction. Thus, a smaller sandstone to shale ratio is necessary to account for the observed positive relief.

4.4 Comparison of Model Results

Results from BasinMod 1D compare well with results from BasinMod 2D. The former indicates that the canyon fill is composed of 65% sandstone and 35% shale, while the latter indicates that the canyon fill is composed of 60% sandstone and 40% shale given default lithological parameters.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The model calculations assume that positive relief observed in sediments directly overlying the Hibernia Paleocene Canyon on the 3D seismic reflection data is due to normal compaction alone. Possible canyon fill lithologies are considered to be those that can account for the positive relief, i.e. possible lithologies will result in a decompacted thickness of Biostrat 12, the Fox Harbour Member, and Unit 14 equal to that of the surrounding formations just outside the canyon.

The BasinMod 1D and BasinMod 2D results for the lithology of the canyon fill are very similar. BasinMod 1D results indicate that the canyon is composed of 65% sandstone and 35% shale at the position of the cross section, whereas BasinMod 2D indicates that the canyon is composed of 60% sandstone and 40% shale. The canyon fill may be a homogeneous mixture of these proportions or it may consist of interbedded sandstone and shale. For example, a canyon fill composed of 165 m of sandstone overlying 110 m of shale can account for the observed positive relief in sediments overlying the canyon.

The results indicate that normal compaction alone can account for the observed positive relief. A canyon fill composed of 60% sandstone and 40% shale is incompressible relative to the surrounding formations, resulting in differential compaction and the formation of positive relief up to 50 m in height on the depth converted section. A pure sandstone canyon fill would undergo less compaction and result in positive relief of greater magnitude than 50 m.

The model results are based on shale with an initial porosity of 0.60 and an exponential compaction factor of 0.51 and sandstone with an initial porosity and exponential compaction factor of 0.45 and 0.27, respectively. These values are considered to be good approximations. Varying these values changes the relative proportion of sandstone and shale. For example, increasing the initial porosity and exponential compaction factor of sandstone results in a greater compaction of the sandstone. Since the sandstone compacts more than a sandstone with the original values, a larger proportion of sandstone (> 60%) in the canyon fill is needed to account for the observed positive relief.

The modeling does not provide a definitive lithology, but helps to constrain what the canyon fill lithology might be. All results indicate that the canyon fill is composed of a large proportion of sandstone. This implies that the canyon fill may be derived from nearby terrestrial sources, i.e. the canyon did not simply fill with shale during a period of transgression. Instead, sandstone was transported from the continental margin and deposited within the canyon. Such knowledge of the lithology of the Hibernia Paleocene Canyon is important in understanding the

Early Tertiary sedimentary system in the Jeanne d'Arc Basin.

5.2 Recommendations

The modeling procedure used in this thesis can be extended to determine the lithology of the canyon fill down canyon. The positive relief observed in western portions of the 3D survey area gradually decreases easternward until it becomes negative in sediments overlying the widest downslope portions of the canyon. This change in relief may be indicative of a change from a sandstone-rich canyon fill to a shale-rich canyon fill. Modeling of the canyon fill would provide an indication of the changes in composition of the canyon fill along the canyon's length.

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