# Baltimore Canyon Trough Mesozoic Carbonate Margin Cores, Offshore USA Atlantic

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## Abstract

In 1984 three wells operated by Shell tested various types of Jurassic-Cretaceous carbonate shelf and margin plays in deep water offshore New Jersey. Eleven cores were recovered: OCS-A 0336 cores R1-4, OCS-A 0337 cores C1-3 and OCS-A 0317 cores H1-4. Representative core intervals on display are keyed to seismic morphology and show litho-biofacies from three geometrically and stratigraphically separate shelf edges: Oxfordian-Kimmeridgian prograded margin (R1+2) and slope (C3), Late Kimmeridgian-Berriasian aggraded margin capped by pinnacle reefs (C2, H3+4), then an extensive deeper-water mounded sponge-rich interval of Berriasian and Valanginian age (R2, C1, H2) and finally a back-stepped Barremian-Aptian reef margin (R1) on prodeltaic shales. Alternatively cores can be facies grouped into deeper-water upper slope microbial(?) mound (C3) and reef complex (R3–foreslope? + R4-reef framework & sands) of the prograded margin, shelf-edge shallow-water skeletal sands (H3+4, C2) in the aggraded margin, and deep-water carbonates capping a drowned shallow-water shelf (R2, C1, H2) then mid-Cretaceous shallow-water shelf-edge oolite (R1). Previously unpublished paleoenvironmental models by Edwin Ringer and Harvey Patten illustrate the depositional facies relationships.

No analogue is perfect, but older (and with the 1999 Panuke gas discovery many more recent) Nova Scotia (NS) shelf-edge wells also sample the Jurassic-Cretaceous gigaplatform margin. Though similar enough to apply the same formational terminology and a very similar vertical depositional progression including 'drowning", the Baltimore Canyon wells in general sample much more carbonate-sand-rich beds. Whereas the NS margin wells sample muddier but much more reef framebuilder-rich beds. The basins have some major difference but these biofacies differences may indicate a "sampling" bias; possibly shallow-water J-K reefs simply grew in slightly deeper water. The best depositional model will integrate both data sets. Degree of dolomitization remains a significant difference.

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## Introduction

The carbonate cores on display result from deep-water drilling by Shell Offshore Inc and partners in the mid 1980's of 3 wells testing the Mesozoic carbonate margins in Baltimore Canyon Trough below the United States Atlantic continental slope offshore New Jersey and Delaware. The exploration results in that round of drilling were discouraging. At the time there were no discoveries in the Canadian part of the carbonate trend as analogues. This is reflected in the Minerals Management Services (2001 and 2003) play analysis and low assessments for the Atlantic outer continental shelf. The discovery of Deep Panuke Jurassic carbonate margin gas in 1999 (Weissenberger et al. 2000) offshore Nova Scotia now gives an analogue to apply to future exploration and a little more optimism. Figure 1 shows the Atlantic margin location of the basins and the Panuke analogue. The Baltimore Canyon wells tested different play types (their informal operational names are the basis of core letter abbreviations of the abstract). SOI et al. OCS-A 0317 of Wilmington Canyon Block 372 ('Hyena' = H 1-4 cores) tested a platform Jurassic-Cretaceous margin "pinnacle play", SOI et al. OCS-A 0337 of Wilmington Canyon Block 587 ('Civet' = C 1-3 cores) tested a Jurassic-Cretaceous near-margin "mesa or mound play" and SOI et al. OCS-A 0336 of Wilmington Canyon Block 586 ('Rhino' = R 1-4 cores) tested a "Lower Cretaceous shelf edge and Jurassic platform structure play". Much of the material contained in this write-up represents the results of work done at that time by Shell geologists (Eliuk, Cearley and Levesque 1986; Karlo

1986, Meyer 1986, Ringer and Patten 1986, Eliuk 1991) particularly litho-depofacies studies in an unpublished 1985 report by Leslie Eliuk and

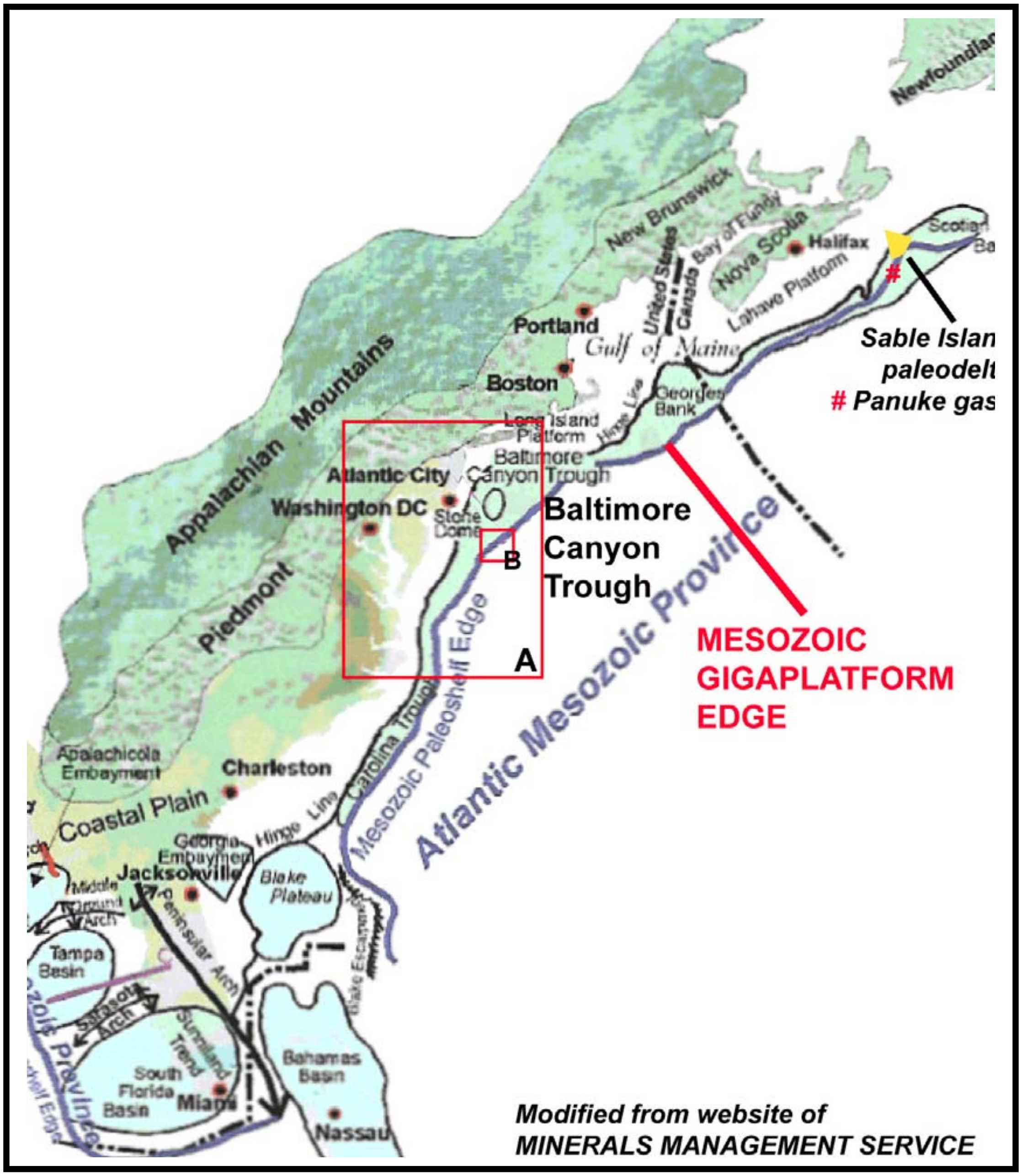


**Figure 1.** Atlantic margin regional physiographic-basin map showing the location of the Baltimore Canyon Trough and Figure 2 a and 2b map outlines. The edge of mid-Mesozoic gigaplatform (Poag 1991) is shown from the southwest Grand Banks to the Bahamas. Deep Panuke gas accumulation just south of the Sable Island paleodelta is the first discovery in the carbonate margin trend.

Rene Levesque and the depofacies models and details of dating of the drowning events in OCS-A 0337 from an unpublished 1987 comprehensive biostratigraphic report by Edwin Ringer and Harvey Patten. Some aspects of this information were published by Meyer (1989) in the context of a siliciclastics-influenced carbonate platform and by Prather (1991) in terms of the petroleum geology. Meyer (1989) more closely follows the stratigraphic stage subdivision used here and gives more details of dating based on Patten and Ringer's work (Table 1 summarizes some of that biostratigraphy). He also sketched block diagrams for the three main platform growth stages (Fig. 13 of Meyer 1989) and showed a comparison of Baltimore Canyon to 3 lines across the Nova Scotia margin taken from Eliuk et al. (1986 talk abstract; Fig. 14 of Meyer 1989). Prather (1991) showed structure maps of the structurally-closed carbonate prospects tested and four core schematics (C1, R1, R3 and R4). A carbonate core not included here is from a back-reef high-energy sand apron (Fig.11 A of Prather 1991) in Tenneco OCS-A 0038 #2 that flowed gas from the older proximal prograded margin 12 km west of the final shelf margin edge. Both papers are worth checking for the seismic, regional setting, sequence stratigraphy and interpretation details. Erlich et al. (1990, 1993) shows detailed seismic lines through or near all 3 of the Shell et al. margins wells to illustrate their ideas on carbonate-platform drowning events. Their dating has significant differences from that of Ringer and Patten (compare Fig. 9 with Erlich et al.'s 1990 Fig. 4) and if they had checked into the Nova Scotian Abenaki Artimon Member of Eliuk (1978) they would have had a decade-old analogue for both East Coast post-Jurassic carbonate drowning and the sponge reef mounds that co-occur with such events in deeper water. Libby-French (1984) and Poag et al. (1990) show the generally far distant relationship of Jurassic-earliest Cretaceous shelf-interior deltaic depocentres from the more basinward carbonate margin on regional maps

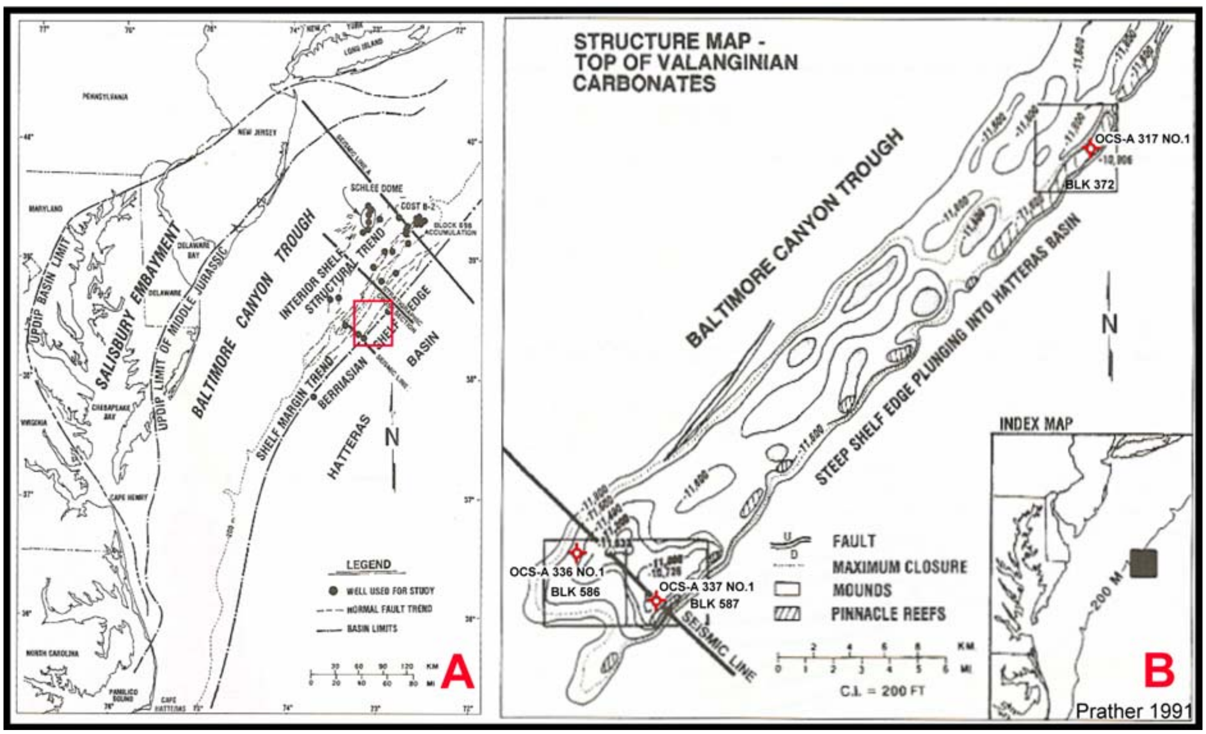


**Figure 2**. Baltimore Canyon Trough maps from Prather (1991): **A**) outline of basinal Trough showing the Late Jurassic-Berriasian shelf margin trend in deep water beyond the present-day shelf edge, **B**) top drowned Berriasian carbonate shelf margin structure map showing the high relief pinnacles-raised rim at the margin and the low relief mounded "mesa" trend just inboard of the margin. The back-stepped Barremian-Aptian margin edge trends sub-parallel to the older edge through the OCS-A 0336 No.1 well (see Prather 1991 Fig.9 for an Aptian structure map)

The Baltimore Canyon cores have only been shown once before publicly (Eliuk and Prather 2005). Unfortunately due to space restrictions all or portions of some cores cannot be shown, but at least 11 short summaries and schematics are included here. Eliuk has reinitiated study of these cores explaining why USA cores were in Calgary in 2005 and are now at the Canada-Nova Scotia Offshore Petroleum Board repository in Dartmouth, but this newer work is on going and will also include a re-examination of the well cuttings when complete. To be fair, Canadian East Coast carbonate cores have already been shown in the United States by me a mere 20 years ago in New Orleans (Ellis et al. 1985). And this presentation mainly reflects the work of 2 decades ago; however it is still appropriate for the 2008 Conjugate Margin conference in Halifax where it may give insights for revived Nova Scotia carbonate margin exploration and development. The 1999 discovery of the deep Panuke gas accumulation by EnCana (PanCanadian) may allow different play ideas to be pursued in American waters when the US East Coast drilling moratorium ends. The updated Abenaki carbonate template that resulted from the newer Nova Scotian wells will help in cuttings and facies studies (Wierzbicki et al. 2002). While the three major mid-Mesozoic reef-reef mound types – coral, siliceous sponge and mud (microbial) mound – were known in the mid-late 1970's off Nova Scotia (Eliuk 1978, Eliuk 1981), the past decades have seen a much better understanding of the reefal relationships and framebuilders and the importance of microbial (rather than "blue-green algal") contribution to carbonate reef and slope sedimentation (Crevello and Harris 1984, Jansa, Pratt and Dromart 1989, Leinfelder 1994, Insalaco 1996, Leinfelder et al. 2002).

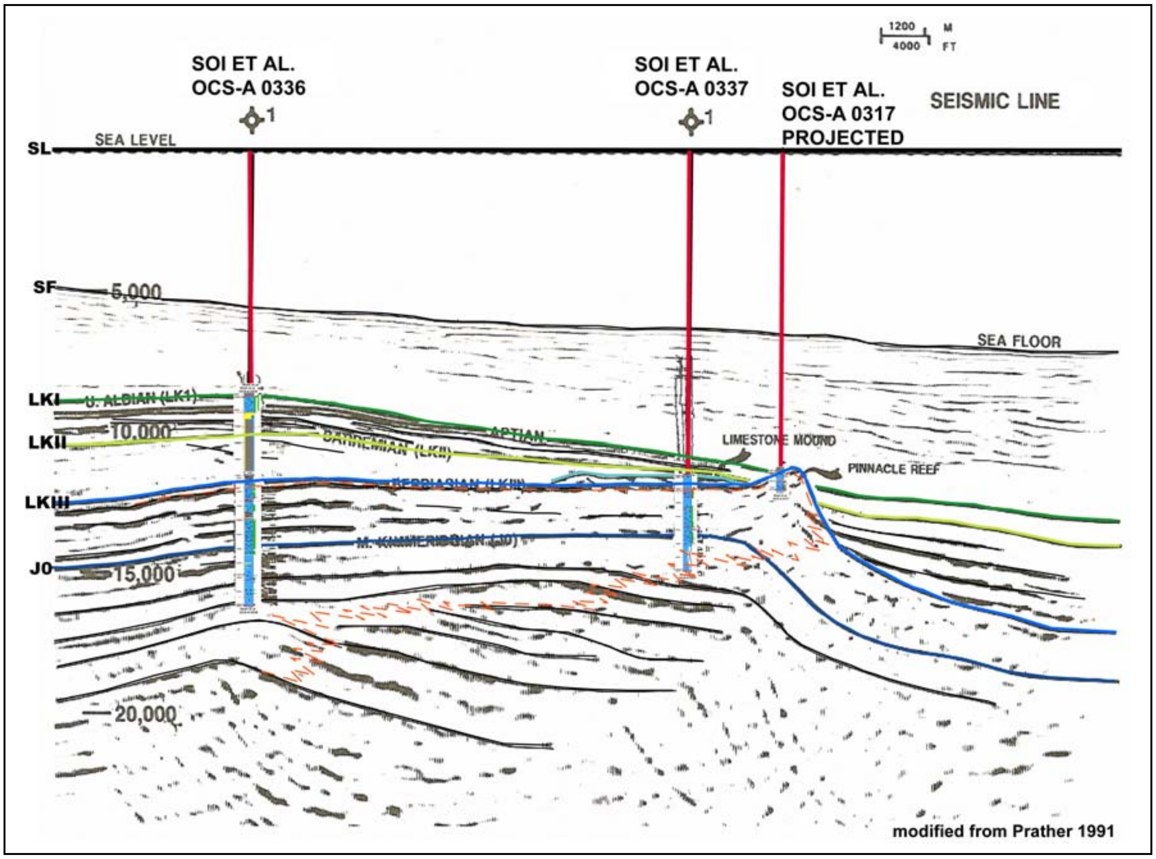


**Figure 3**. Dip seismic line through OCS-A 0336 and OCS-A 0337 with OCS-A 0317 projected from northeast (see Fig 2b for location of line and wells). Note the raised rim or pinnacle reef right at the margin edge tested by OCS-A 317 on the landward flank down from the crest and the limestone "mesa" or mounded unit behind the margin tested by OCS-A 0337. The mounded unit and the double reflector at LKIII are an expression of the deeper water 'drowned' shelf of stage III; beneath that is the shallow shelf aggradational Stage II best developed near the final margin edge and beneath that is the youngest portion (Oxfordian-Kimmeridgian) of the progradational Stage I which begins in the Middle Jurassic up to 60 km to the west of the margin termination in the Berriasian. Regional rotation on a landward fault system gives large areas of shelf closure, which OCS-A 0336 tested, along with the back-stepped Aptian margin. The dashed red line encloses the shallower-water shelf and margin facies.

## Baltimore Canyon Carbonate Lithologies and Depositional Interpretations

The 3 wells were drilled in over 1.5 km (5000 feet) of water testing different prospects always in closure defined by seismic (Fig. 2 a & b and Fig. 3 modified from Prather 1991). Data on depositional environments in the Wilmington Canyon area of Baltimore Canyon trough can be derived from at least four sources: seismic stratigraphy/geometries, lithologic information from drill cuttings in three wells, core lithologies in 11 cores and paleontological determinations of microfossils, dinoflagellates/palynomorphs and calpionellids from the cores and cuttings. The seismic sequence and paleontological data are dealt with in more detail elsewhere (Meyer 1989, Prather 1991) and are summarized here in Table 1 and 2. Presenting core and cuttings data on schematic lithologs and dip-oriented sections derived from seismic includes aspects of these and repeats some paleontological dating where appropriate (Fig. 3 to 5). Generalized lithologic columns based mainly on cuttings supplemented by standard and sidewall cores are shown in Figure 4 with the location of the cores listed by facies. The cuttings data are summarized in percentage "pie" diagrams of the principal, readily identified, lithofacies (Fig. 5). Thus the shelf interior, prograding and aggrading margins and slope seismic geometries can be linked to lithologic control. And another major facies association, the drowned deep-water carbonate shelf can be added since it cannot be defined by seismic alone. In summarizing the depositional trends and history of these carbonates Meyer (1989) used a threefold 'stage' subdivision (see Fig 5.). Stage I (early Kimmeridgian) is a continuation of prograding platform growth, followed by Stage II (late Kimmeridgian-early Berriasian) aggradational platform growth including a late development of margin pinnacles or raised rim then the final Stage III (late Berriasian-early Valanginian, including the 'mesa' or mound event) is deeper-water shelf carbonate deposits capping the 'drowned' platform. There was then a major back step of the shelf followed by Hauterivian-Barremian prodeltaic shale and sand deposition to be eventually capped by an Aptian oolitic shelf margin.

Use of microfossil biostratigraphy and paleoecology in concert with lithologic and macrofossil features seen in core and cuttings allowed Edwin Ringer with Harvey Patten (unpublished 1987) to develop a set of paleoenvironmental models across the shelf for the Late Jurassic-early Cretaceous (Neocomian). Figure 6 shows the early Kimmeridgian (uppermost part progradational Stage I and lower aggradational Stage II growth, Meyers 1989). Figure 7 shows the Late Kimmeridgian/Portlandian (upper part of aggradational Stage II growth, Meyers 1989) with high-energy shoals and then pinnacle reef growth in a catch-up phase into the Berriasian. Figure 8 shows the (early?) Valanginian with major back stepping of the shallow-water carbonate margin leaving the former outer carbonate platform 'drowned' in deeper-water Artimon Member type sponge-rich facies (Stage III deep shelf system in part, Meyers 1989). Note that the Berriasian depending on the location has aspects of both of Meyers' Stages II and III and Ringer's second and third paleoenvironmental models. Figure 9 shows the OCS-A 0337 well log character through

**Table 1. Summary of biostratigraphic dating in carbonates of Shell et al. wells (from Ringer and Patten in Meyer 1989).**

(Interval tops are approximate and some placed partly with assistance of seismic reflectors; depths in feet as drilled)

| AGE | (datum) | OCS-A 0336 | OCS-A 0337 | OCS-A 0317 |
|---|---|---|---|---|
| Early Cretaceous (Neocomian) | | | | |
| Early? Valanginian | (G) | ~11150'? (in post-Abenaki shale) | 10970' | absent (= lacuna) |
| Late Berriasian | | 11260' | 11250? | 10970' (top Abenaki) |
| Early Berriasian | (F) | 11850' | 11460' | 11200'?? |
| Late Jurassic | | | | |
| Portlandian | (E) | 12330' | 11650' | not penetrated |
| Late Kimmeridgian | (near C) | 12970' | 12255' | |
| in Kimmeridgian | (C) | 13030?? | | |
| Basal Kimmeridgian (near-Oxfordian?) | (A) | 15690' (basal 310') | not penetrated | |

**NOTE on major sequence-seismic marker ages:** (see Fig. 6 for relationships of LKIII in OCS-A 0337 and Prather 1991 figures 4 and 5)

LKI - about level of mid Albian lacuna (Aptian carbonate margin with OCS-A 0336 core #1 between LKI and LKII = LKIA)
LKII - about level of Late Barremian lacuna
LKIII - about level of Valanginian-Early Hauterivian (mid Neocomian) lacuna = "Mesa" event and underlying carbonate (LKIV - of Meyer 1989 and ex-JO) about Berriasian-Valanginian - TOP carbonate and LKIII of Prather (1991)
JO - revised in Prather 1991, about latest Jurassic Portlandian-mid Kimmeridgian

**Table 2A. Summary of Baltimore Canyon Trough Carbonate Reservoir Rocks (from Prather 1991)**

| | CNL/FDC porosity | | | | Permeability (based on perm plug measurements*) | | |
|---|---|---|---|---|---|---|---|
| Facies/Lithology | number of beds | Sum (m) | Avg (%) | Range (%) | number of beds (core) | Avg K (md) | Range (md) |
| Prograded shelf margin LS | 277 | 1823 | 2.4 | 0.0-17.0 | 148 (C3?) | 0.34 | <0.001-17 |
| Aggraded shelf margin LS | 189 | 1015 | 8.5 | 1.5-26.0 | 43 (C2, H3, H4) | 5.10 | <0.01-156 |
| Limestone buildups | 3 | 65 | 12.2 | 11.0-13.0 | --- | --- | --- |
| Chalky Tubiphytes wk/pkst | 84 | 26 | 6.3* | 0.0-31.1* | 84 (C1, H2, R2) | 0.47 | <0.001-12.6 |
| Shoal-water oolite grainstone | 53 | 222 | 17.0 | 1.0-36.00 | 23 (R1 Aptian) | 2.45 | <0.001-12.2 |

**Table 2B Core Porosity and Permeability Summary (depths given in original drilled units = feet)**

| Well-Core Number | | Age (Facies group #) | Interval (Feet) | Net Feet | Porosity Average (Range) | Permeability Range |
|---|---|---|---|---|---|---|
| OCS-A 0317 **#2** | (H2) | Late? Berriasian (1) | 10975-11006.4' | 30.5' | 1.34% (0.4-2.4%) | 0.005-4.1md |
| OCS-A 0317 **#3** | (H3) | Early Berriasian (2) | 11252-11264' | 6.7' | 5.01% (3.8-5.5%) | 0.011-1.7md |
| OCS-A 0317 **#4** | (H4) | Early Berriasian (2) | 11563-11586' | 23' | 2.61% (0.8-6.2%) | 0.01-0.13md |
| OCS-A 0337 **#1** | (C1) | Early? Valanginian (1) | 11012-11030.8' | 31' | 14.47% (--) | -- very low-chalky |
| OCS-A 0337 **#2** | (C2) | Berriasian-Portlandian (2) | 11551-11564.2' | 13.2' | 12.67% (--) | -- low |
| OCS-A 0337 **#3** | (C3) | Kimmeridgian (4) | 14470-14496.7' | 27' | 1.65%% (--) | -- very low |
| OCS-A 0336 **#1** | (R1) | Aptian (2 post-Abenaki) | 9036-9058.6' | 23' | 17.22% (10-24.1%) | 0.5-12.2md |
| OCS-A 0336 **#2** | (R2) | Late? Berriasian (1) | 11605-11629.2' | 25' | 6.97% (3.7-13%) | 0.012-2.0md |
| OCS-A 0336 **#3** | (R3) | Early Kimmeridgian (3) | 14882-14912' | 29' | 2.71% (0.5-6.3%) | 0.022-5.2md |
| OCS-A 0336 **#4** | (R4) | basal Kimmeridgian (3) | 15970-15999' | 30' | 2.86% (0.7-6.4%) | 0.011-1.4md |
| | | | | 238.4' carbonate core | | |

Depofacies groups: 1 – 'Artimon Member' deeper water 'drowned' shelf (tubiphytes-sponge marls, chalks, microbialites) 2 – shelf-edge skeletal-oolitic sands 3 – reef complex of early shelf edge and interior 4 – deeper water upper slope? microbial mud mound

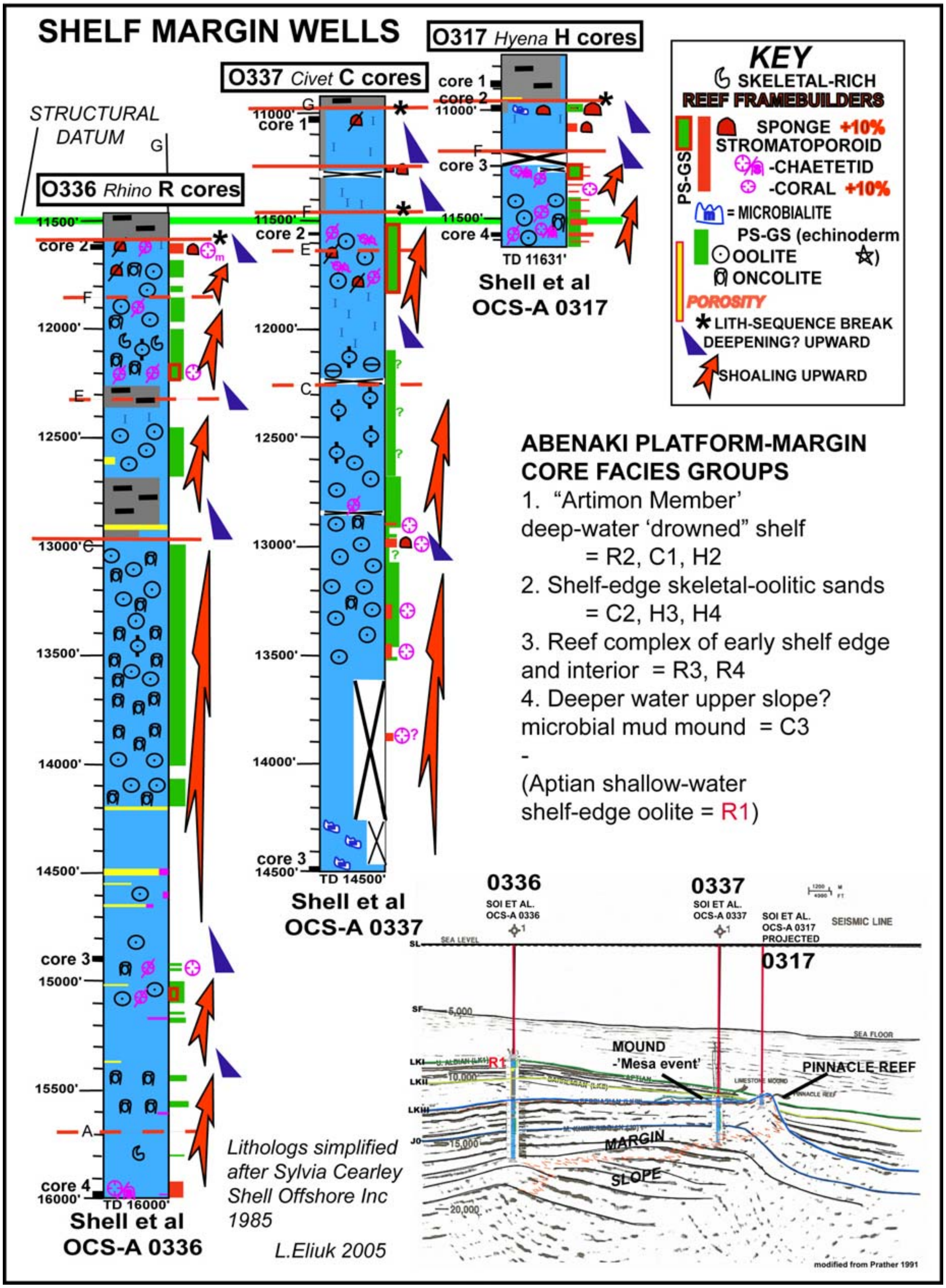


**Figure 4**. Shelf margin wells schematic lithologs of Shell OCS-A 0336, 0337 and 0317 based on cuttings and core logging. See Table 1 for approximate ages of biostratigraphic markers (letters on left). The cores have been grouped by major depositional facies and their position is shown on the logs. See Table 2 for summary of porosity and permeability measurements. The shoaling and deepening trends are generalized and highly interpretive. The relationships of the wells are shown on the seismic insert (see Fig.3).

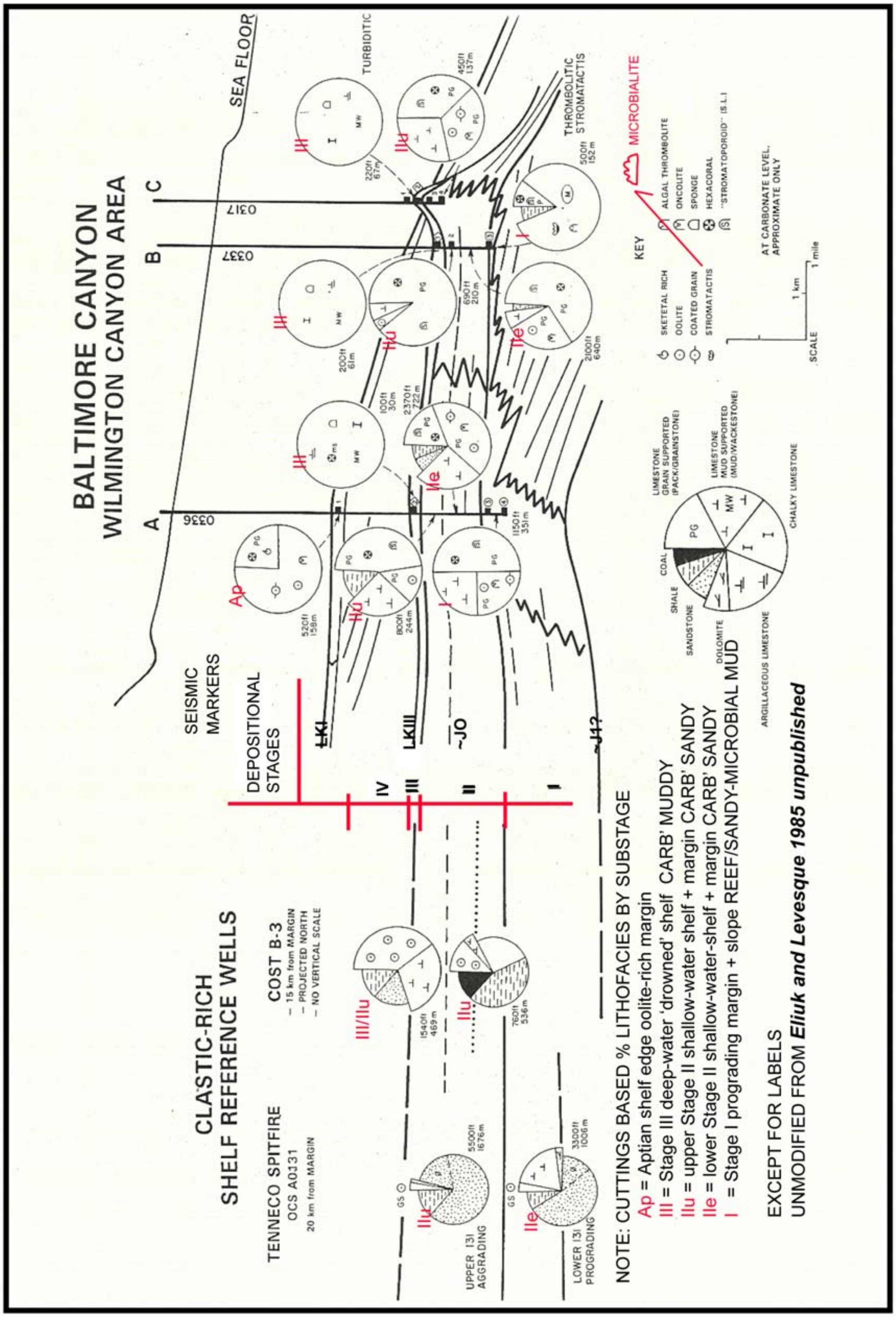


**Figure 5**. Percentage lithofacies from well cuttings by depositional growth stages (see Meyer 1989 for more interpretation and a complementary block depositional model). Note the large amount of skeletal/framebuilder and oolitic/oncolitic grainstones-packstones indicating relatively open high-energy shelf for Stage II. Landward there is a major change to a siliciclastics dominated system. The widespread sponge-Tubiphytes-rich marly-chalky limestones indicate stage III 'drowning'

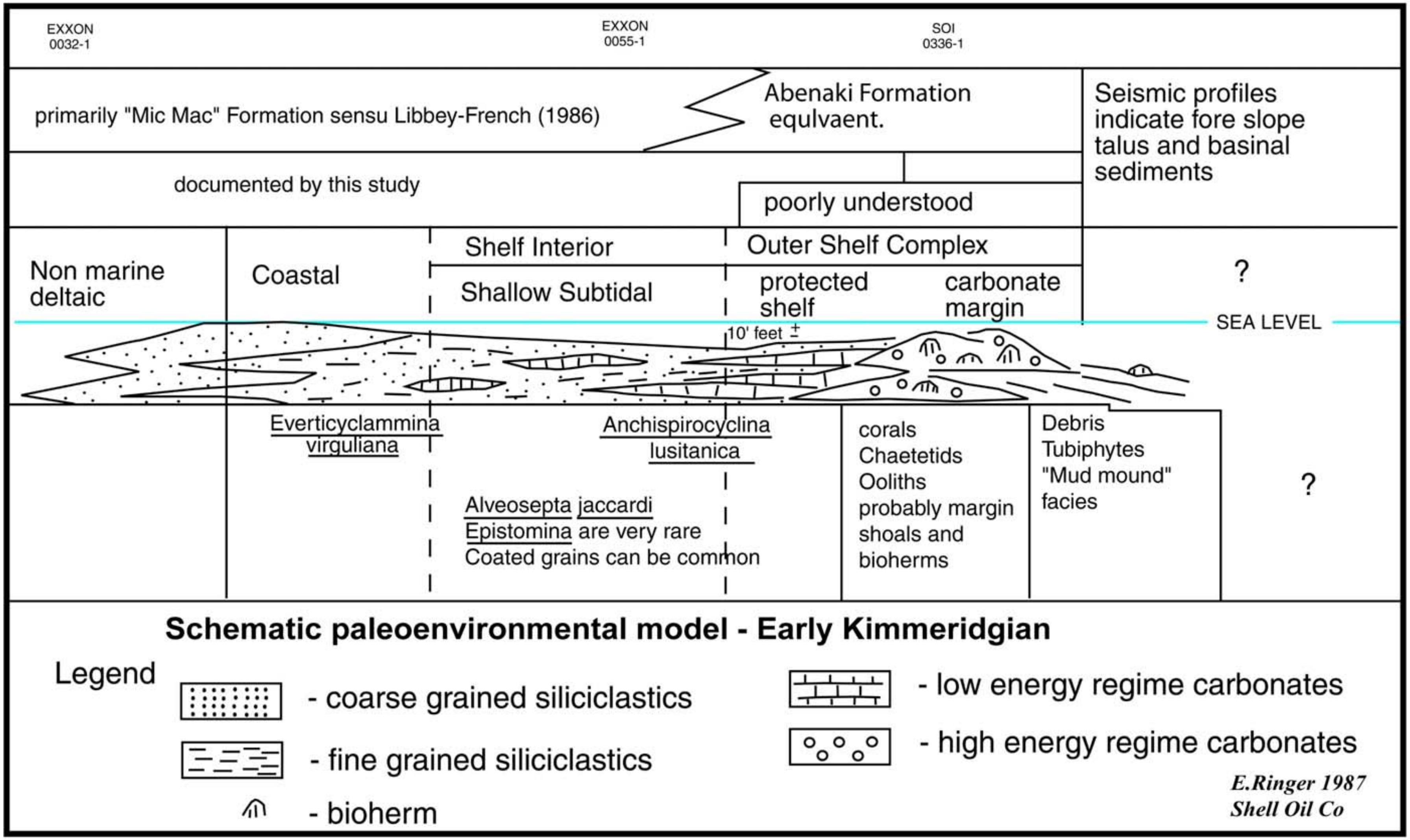


**Figure 6.** Schematic paleoenvironmental model of the Early Kimmeridgian of the Baltimore Canyon basin, with some significant environmental incidators noted. Cited wells are illustrative. During stillstand or relative regression siliciclastics and carbonates prograde basinward over a shelf with little accomodation space. Occasional transgression causes shoreward migration of the carbonate regime and aggradation. "Corallian-lke" deposition took place during a period of gradual (variable) subsidence.

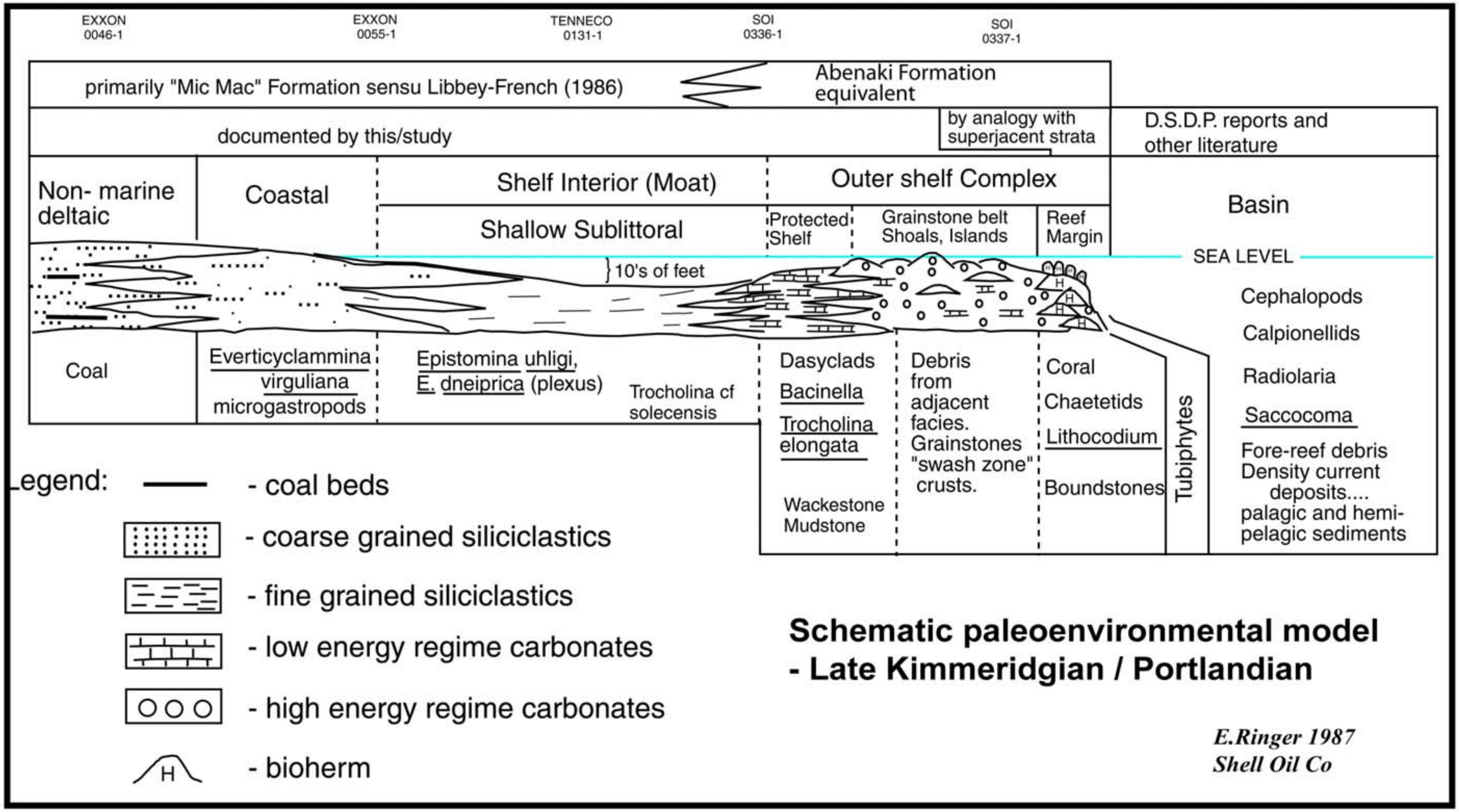


**Figure 7.** Schematic paleoenvironmental model for the Late Kimmeridgian/Portlandian found in the Baltimore Canyon Basin, with some significant environmental indicators noted. Cited wells are illustrative. Shelf is sudivided into coastal, paralic, shelf interior, intra-shelf basin ('moat' facies of Eliuk 1978) and margin "pinnacle" complex. This model reflects the Stage II aggradational growth style with greater relative platform subsidence.

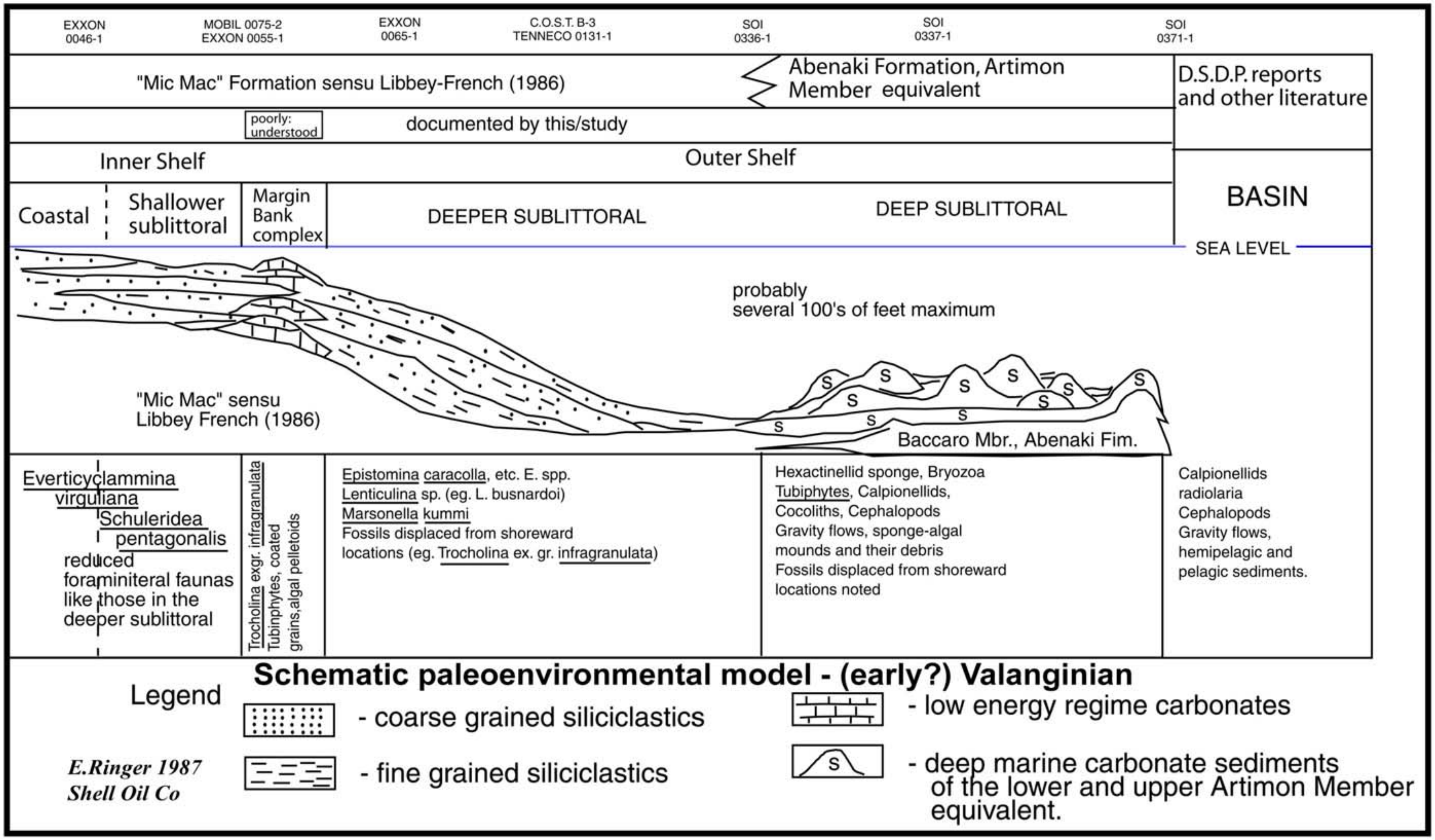


**Figure 8.** Schematic paleoenvironmental model for the (early?) Valanginian of the Baltimore Canyon Basin, with some significant enviromnental indicators noted. Cited wells are illustrative. Note the shoreward displacement of margin bank (possible Knowles equivalent) due to eustatic rise in sea level during the earliest Createaceous.

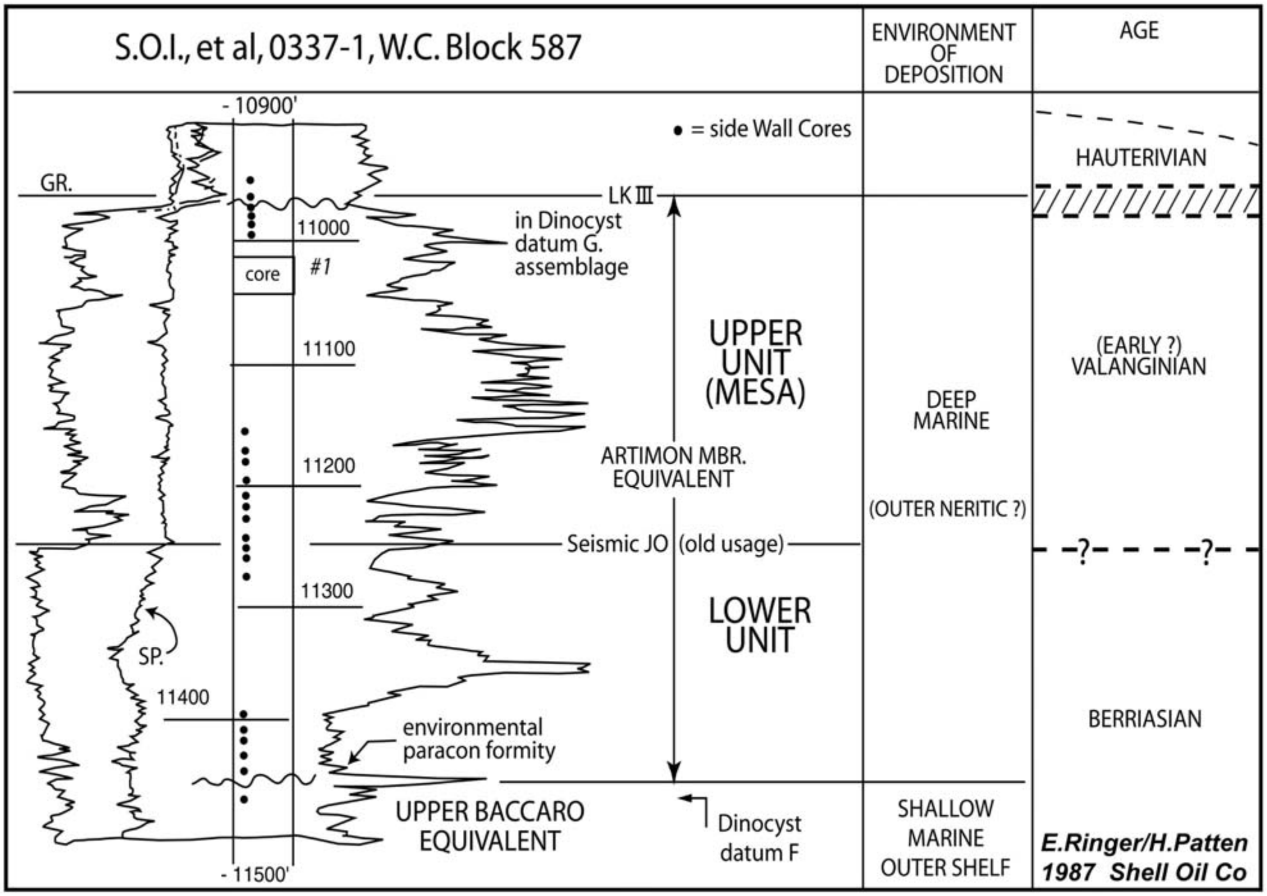


**Figure 9.** Annotated mechanical log of the most complete section of the uppermost Abenaki Formation, Artimon Member equivalent noted in the Baltimore Canyon Basin and as penetrated by the S.O.I. et al. OCS-A 0337-1 well.

the uppermost Abenaki that has the youngest and most complete carbonate section of the Jurassic-Cretaceous carbonate shelf in Baltimore Canyon. It shows the complexity and multiple nature of the drowning of the Abenaki with the Valanginian apparently being absent (lacuna due to bypass and submarine winnowing?) in OCS-A 0317 above the 'catch-up' to 'give-up' pinnacle reef growth and in the overlying shales in OCS-A 0336.

Generalized lithologic columns based mainly on cuttings supplemented by standard and sidewall cores are shown in Figure 4 with the location of the cores listed by depofacies. The cuttings data are summarized in percentage "pie" diagrams of the principal, readily identified, lithofacies (Fig. 5). The cores allow more detailed interpretation of the depositional environments as well as being the source of data for diagenetic studies (see Meyer 1989). That core data is presented as schematic, generalized logs with biota, carbonate texture, interpreted environment and comments on diagenesis briefly noted (Fig. 10, 11, 12, 13).

## Baltimore Canyon Cuttings Lithofacies

Analysis of thick cuttings intervals using simplified lithofacies permits reasonable interpretation of depositional environments and vertical stage-to-stage changes. The often-cited cuttings' draw- backs of caving problems and properly logging diverse rock types in a single sample are thereby minimized. Based on cuttings litholog data the following lithofacies can be distinguished in carbonates of the three Shell Wilmington Canyon wells:

1) Framebuilder/skeletal grain-supported limestone (grainstones and packstones and lesser amounts of boundstones which like rudstones and floatstones are not easily identified in cuttings; framebuilders include corals, coralline sponges (stromatoporoids & chaetetids) and lithistid/siliceous sponges,

2) Oolitic/oncolitic grain-supported limestone (ooids and superficial ooids or coats often on skeletal fragments but also on indistinguishable clasts, larger oncoids or pisoids),

3) Muddy limestones including argillaceous or chalky limestone (wackestones and mudstones including floatstones; sponge-rich wackestones/mudstones and thrombolitic mudstones are shown),

4) Non-limestones a) Sandstone, b) Shale (and siltstone), c) Coal (in Cost B-3 inner shelf reference well), and d) Dolomite (in Tenneco OCS A 0131 inner shelf reference well).

These lithofacies have been displayed as percentage “pie” diagrams on the schematic dip section (Fig. 5) subdivided by major depositional stages I, II, III and seismic depositional environments - slope, aggrading/prograding margins and shelf interior. Two nearby Jurassic inner shelf interior wells are included to show the lithologic changes behind the margin. Note that in Figure 5 the Stage II aggrading carbonates of 0336 and 0337 are subdivided into a thinner upper unit and a lower unit. Thus a seismic stratigraphic interval with features indicating greater flooding of the shelf and inception of pinnacle growth at the margin in uppermost Stage II can be shown lithogically. In Figure 5, Stage II carbonate lithologies are shown combined and another clastic-rich shelf interior well is added.

The three Shell Wilmington Canyon wells are dominated by grain-supported limestone. Skeletal/framebuilder limestones (including possible boundstones) dominate both the aggrading and prograding margins. Oolitic/oncolitic grain-supported limestone increases towards the shelf interior along with siliciclastics. Carbonate mud content as well increases towards the shelf interiors but is always in minority proportions. However, on the slope in the lower 150 m of 0337 carbonate mud is dominant. In both the shelf interior and slope zones note the discrete presence of shale. This lower velocity material gives a bedded character on seismic as opposed to the massive character of the margins. The younger, Stage IV, Aptian age carbonate margin, which caps a thick shale wedge, differs from the Jurassic margin in both much greater oolitic content and being 100% grain-supported.

Over a relatively short distance of a few miles there is a change from 100% carbonate near the margin to less than 50% or even 25% in the inner shelf interior. This rapid gradient to siliciclastics is in striking contrast to the situation on the Nova Scotia shelf. There either the transition is very broad and gradual as on the western shelf or the proximity to the Sable Island deltaic depocentre is reflected in relatively high siliciclastic content of the carbonate margin. High amounts of coals in Cost B-3 reflect both a humid climate and the nearness of shoreline facies during lower Stage II. During uppermost Stage II carbonates, especially non-skeletal oolites, are much better developed indicating the flooding of the shelf and initiation of a deepening trend seen on seismic stratigraphy.

This relative sea-level rise is seen in 0336 and 0337 by the marked reduction in oolite and sandstone of uppermost Stage II compared to lower Stage II. The Stage III deposition is in marked contrast to the underlying carbonates. A uniform, low-energy, argillaceous or chalky limestone, rich in lithistid sponges and *Tubiphytes*, blankets both the shelf margin and interior. This Berriasian to Valanginian deposit is interpreted as a deep-water drowned shelf. Figure 9 (Ringer and Patten) shows the age relationships of the "Artimon member" drowned facies of stage III and the 'mesa' or mounded unit whose topography most probably results from sponge mound growth. Paleontological dating suggests that a portion of the aggrading shallow water grainstones in 0317 may be as young as deep-water carbonates behind the shelf-edge in 0336. Thus "pinnacle" development may be a result of rapid drowning and persistence of shallow carbonate sedimentation for a time at the highly productive shelf edge. This low energy unit is the time and facies equivalent of the Artimon Member that caps shallow-water Abenaki carbonates of the Nova Scotia shelf.

## Baltimore Canyon Core - Depositional Interpretations

Eleven cores were taken in the three Shell wells of the Wilmington Canyon area. These are illustrated by schematic vertical logs in figures 10 to 13 and as photographs of representative lithologies on Figures 14 to 16. Limestone classification is based on Embry and Klovan (1971). A summary diagram (Fig. 4), showing schematic well lithologs, which were also used on the seismic section through these wells (fig. 3), groups the cores into similar depositional facies. Excluding the Aptian shelf margin oolitic Core #1 (R1) in 0336 and the Albian slope shale Core #1 (H1) in 0317, the cores can be placed in four general environments of the Late Jurassic-Neocomian carbonate complex. Their relationship to the seismic stratigraphic stages and cuttings lithofacies is indicated in brackets.

Thus three cores (H2, C1, R2) in different wells at the top of the carbonate section represent a drowned Berriasian-intraValanginian deep-water shelf (Stage III - marly sponge limestone). Three cores (H3, H4, C2) in two different wells occur within the aggrading margin and indicate shallow-water skeletal sands with minor reefal and oolitic/ oncolitic layers (Stage II - framebuilders/skeletal and oolitic/oncolitic grain-supported limestone). Two cores (R3, R4) are part of a reef complex developed in the upper part of the prograding margin where it interfingers with argillaceous shelf interior beds (Stage I - framebuilder grain-supported and boundstone limestone). One core (C3) of lime mudstone is seismically at the top of the slope and can be interpreted as a downslope mud mound (Stage I - muddy stromatactis/thrombolitic limestone).

### **<u>Well 0317</u> ("pinnacle" play)**

Well 0317 tested the landward side of a high-relief build-up located at the edge of the Abenaki ('JO') carbonate margin. Dipmeter data reflect the landward position, in that the shales well above the build-up have regional/depositional dip southeast into the basin but 300 feet above carbonates dip landward to the southwest. This southwest dip continued through the core H2 interval where slope sedimentation and inclined bedding can be interpreted (see below) but resumes a regional southeast dip in shallow-water carbonates as seen in core #4 (see below) near the base of the well. The age of the shallow-water carbonates in 0317 cores H3 and H4 is younger, Early Berriasian, than similar facies in the more shelfward 0337 core C3, Berriasian-Portlandian. Thus shallow carbonate sedimentation continued at the immediate margin giving 'pinnacle'-like bathymetry when it had ceased back on the shelf.

**Core #1** (H1 - not shown) - is lower Cretaceous (Albian) glauconitic, calcareous shale with minor breccias but of younger age than even the Lower Cretaceous (LKII) carbonate margin. This core has surprisingly high average porosity (13.7%) and some permeability to 24 md (fractures?). Perhaps this is chalky porosity preserved at the shallow effective burial depth of only 4000 feet or so.

**Core #2 (H2)** - is sponge-clast and *Tubiphytes*-rich microbial(?) lime mudstone to wackestone with inclined-bedded argillaceous calciturbidites and debris interbeds. Stromatactis is common in the muddy beds but coarse (submarine?) fibrous cement was not seen but micritic submarine cement with geopetals due to microbialite activity is inferred. It is interpreted to be a deep-water slope deposit of multiple origins. These include *in situ* microbialite growth, *in situ* hemipelagic/periplatform ooze interbeds, and debris derived from deep-water sponge reefal beds growing at the apex of the pinnacle. Low average porosity (similar to core C3 in 0337 also interpreted as a slope deposit) suggests that early porosity occlusion by submarine micritic cements and mud infill probably associated with microbial activity. Of relevance to this core and 0337 Core #1 is the inter-reefal beds lateral to the relatively deep-water Jurassic sponge-algal (microbial?) buildups of southern Germany (Flugel and Steiger, 1981). In a similar manner, they consist of burrowed, tuberolithic (irregular calcareous lumps with diverse micro-structure, in part sponge clasts) wackestone to marly mudstones with sponge fragments and spicules, lithoclasts and *Tubiphytes*.

**Core #3 (H3)** - is a skeletal floatstone with grainstone matrix deposit with minor bored, hexacoral-hydrozoan/stromatoporoid boundstone layers. It is interpreted as a very shallow-water, high-energy deposit possibly in a reef flat setting although the skeletal fragments are quite small in size suggesting a more distal location. Porosity is primary interparticle and leached molluscs and hexacorals.

**Core #4 (H4)** - is similar to core #3 with rudstone to floatstone beds interspersed in grainstone to packstone. There is less obvious leaching, and blocky spar calcite infill is pervasive. There is some early isopachous cement (submarine?) as well. Small oncoids coat much of the skeletal debris and a single oncoid is of centimetre size making this core a bit more like the reef-flat core #4 of Acadia K-62 off Nova Scotia where the "oncolite" facies of the Abenaki Formation off Nova Scotia was defined (Eliuk 1981).

## Well 0337 ("mesa or mound play")

This well tested areally extensive near-shelf margin domal or plateau-like features. After drilling they were found to be slightly argillaceous, chalk or chalk-like deposits of high porosity but low permeability. There was little or no age gap between the chalky limestone and the overlying shale. As well coccoliths were recovered from the limestone. Ed Ringer (Shell Oil paleontologist) had initially interpreted them as deep-water (slope?) carbonates. We believe the "mesas" are deep-water (not slope) constructional features and are shown as such in Ringer's Valanginian paleoenvironmental model (Fig. 8). They would probably have formed at similar depths to the Artimon Member sponge reef at the top of the shelf-edge in Demascota G-32 off Nova Scotia (Eliuk 1978) but perhaps in an area of more rapid pelagic and benthic sedimentation. In short the Baltimore Canyon Abenaki 'JO' carbonate was "drowned" just as the Abenaki further north was with the differences in ages either real or possibly due to dating problems (Eliuk and Levesque 1989).

**Core #1 (C1)** - is a chalky slightly argillaceous burrowed, sponge-rich lime floatstone to wackestone with numerous *Tubiphytes*, crinoids, ostracods, and sponge spicules. There are rare thin grainstones and *in situ* lithistid sponge boundstones. It is interpreted as a deep-water chalk/limestone on a drowned carbonate platform. Porosity is so fine that it is not visible in thin section. There was no evidence in the macrofossils of leaching. The Valanginian age (middle Neocomian) makes it slightly younger than the JO carbonate elsewhere just as the Artimon is younger than the bulk of the Abenaki (Baccaro Member) in the Nova Scotian shelf.

**Core #2 (C2)** - is a skeletal-oolitic lime grainstone with fragments of hexacorals, common hydrozoans/stromatoporoids (*sensu lato ie*. chaetetids etc.), molluscs, *Tubiphytes* and oncoids. The clast size seems finer than the 0317 grainstones and the presence of oolites suggests slightly more restricted (salinity or water variability to allow precipitation) though still high-energy conditions in a very shallow water setting. Porosity is quite good due to primary interparticle spaces and some leaching of molluscs.

**Core #3 (C3)** - is a very light colored, lime mudstone with abundant stromatactis and later stylolitization with one mudstone clast layer at the top of the core. *Tubiphytes*, foram-serpulid tubes, rare clotted possible algal texture (thrombolites), thin walled bivalves, ostracods and sponge spicules occur. Some of the stromatactis is lined by thin isopachous (probably submarine) cement. There are often multiple layers of geopetal mud fill that is occasionally inclined. The core is interpreted as a somewhat deeper water mud mound deposit. Seismically Core #3 appears to come from prograding slope or clinoform beds. Thus it may be a down-slope mud mound though there was no impression of inclined bedding in the core. Compared to Nova Scotia, it is very similar to Acadia K-62 Core #5 mud mound unit although that core had more shallower-water derived clasts, occasional *in situ* delicate branching hexacorals, more thrombolitic-algal textures (with included bedding!) but lacked the submarine(?) isopachous rim cements (Eliuk 1981, Jansa et al. 1989). Therefore 0337 core #3 might have formed a slightly deeper water than Acadia K-62 core #5 but shallower than the stromatactis mud mound in Demascota G-32 core #5.

**Well 0336** ("Lower Cretaceous shelf edge and Jurassic platform structure play"):

Well 0336 tested the Lower Cretaceous Aptian shelf edge (LK I) as well as the underlying Abenaki 'JO' carbonates in anticlinal structure along the axis of a landward "flexure" discussed below. The LKI margin was anticipated to be in high-energy oolitic facies, which in fact was the case, and there was associated good porosity but only fair-poor permeability. It should be remembered that since the well was drilled in 5838 feet (1779m) of water the effective burial would be less than 4000 feet (1220m) which much reduces the porosity-destructive effect of burial so critical to Abenaki reservoir development (or lack of it).

**Core #1 (R1)** - from the Lower Cretaceous (Aptian) shelf edge is an oolitic grainstone with some oncoids and fragments of bivalves and hexacorals. Porosity occurs mainly as intergranular spaces with chalky and trace fossomoldic types. It is interpreted as a moderate to high-energy shallow water ooid bar complex localized on a shallowing-up siliciclastic (deltaic?) shelf margin.

**Core #2 (R2)** - is an argillaceous burrowed (chalky?) lime floatstone with wackestone matrix having plentiful *Tubiphytes* and sponges (both in growth position boundstones and as clasts). Thus it is similar to the chalky core #1 in Shell 0337 except that *Microsolena* (a unique, often platy hexacoral) is also present *in situ* and as fragments. Humic(?) or solid hydrocarbon material occurs in some cemented fossils. Porosity is very fine and no leaching is apparent. It can be interpreted as a relatively deeper water carbonate deposit formed at the end of Abenaki 'JO' carbonate deposition. It is slightly older than the sponge-reef derived debris and slope beds of 0317 core #2 but in shallow enough water that a specialized hexacoral (*Microsolena*) could grow *in situ*.

**Core #3 (R3)** - contains at least three lithologies: fossiliferous calcareous black shale, very argillaceous lime floatstone to hexacoral boundstone and (at the base of the core) clean, finer, skeletal lime grainstone-packstone. Above this basal grainstone, the core can be viewed as a shallowing upward sequence from burrowed silty shale, up into oncolitic argillaceous lime floatstone into hexacoral (as massive and tabular *in situ*, occasionally rounded debris, and including microsolenids) rudstone and framestone capped by a (?)deeper-water calcareous shale with crinoids up to a centimetre. Some of the shalier beds show low but discernable inclined bedding. A crushed but not displaced crinoid calyx shows periods of quiet water sedimentation. Borings in corals are filled with argillaceous matrix. There is neither visible porosity nor evidence of leaching. Some thin layers of coaly or solid hydrocarbon material occur in the micaceous shale and dull black blebs (solid hydrocarbon?) occur in some cemented *Microsolena* and predate recrystallization of some corals.

**Core #4 (R4)** - consists of hexacoral-hydrozoan/stromatoporoid (S.L.) floatstone to framestone with large crinoid ossicles overlying a finer grained skeletal-crinoidal packstone. As in core #3 the crinoids are very large, borings are common, and there are seams of coaly or solid hydrocarbon matter. Unlike core #3, hydrozoans/stromatoporoids (S.L.) are much more common and may be as plentiful as the hexacorals. There was no visible porosity.

Cores #3 (upper-middle reefal foreslope depofacies) and #4 (low energy reef-forereef depofacies) seem most easily interpreted as parts of reef complexes apparently located back on the carbonate shelf on an intrashelf high or possibly within the prograding margin complex. Thus there is an interbedding of shelf interior-derived clay and siltstones and shelf margin (or patch) reefal framestones and upper foreslope carbonates. Apparently shale and presumably nutrient enrichment were not as much a reef-growth inhibitor in the Late Jurassic as they are in modern shallow-water coral reefs.

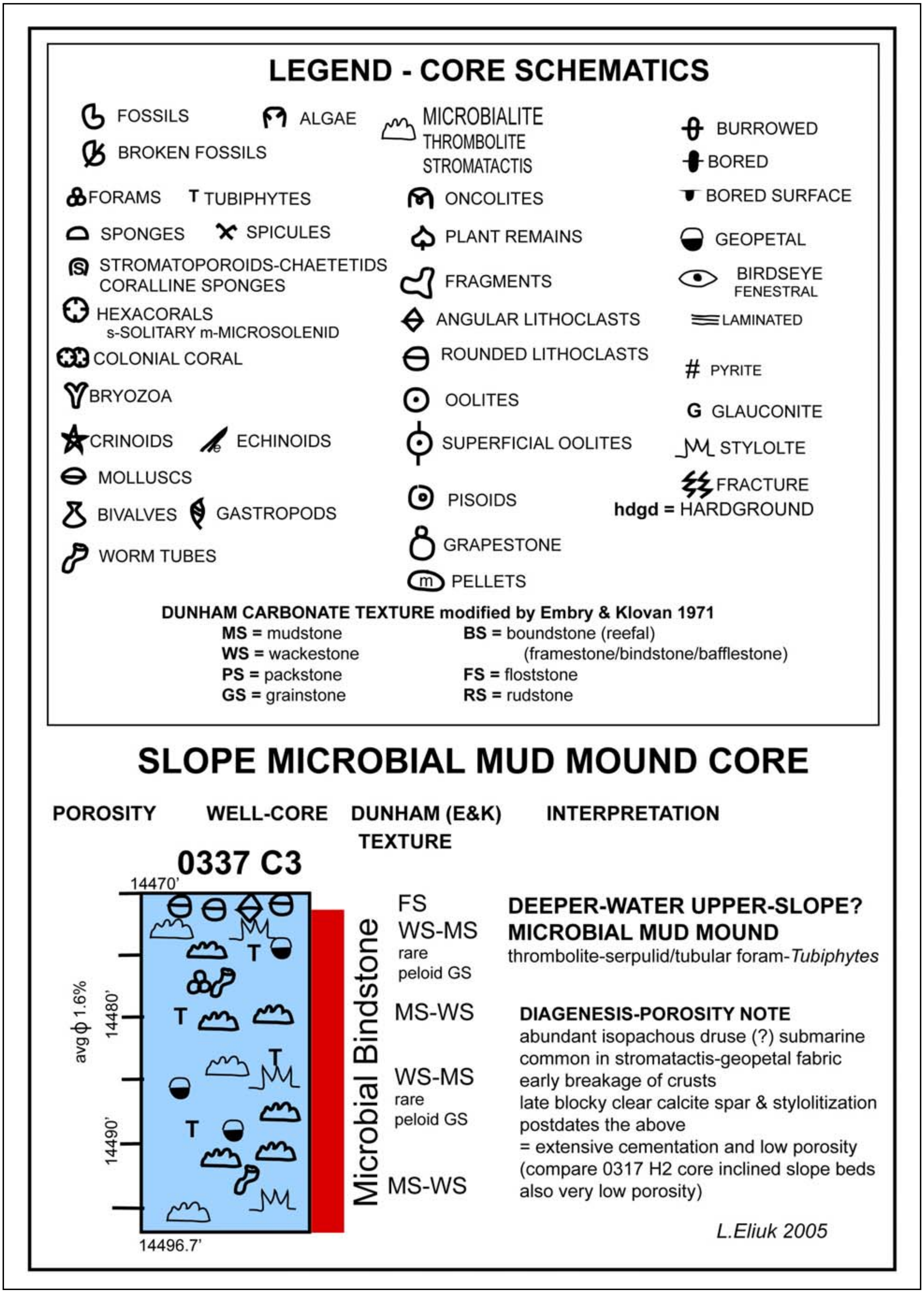


**Figure 10.** Core symbol legend and schematic of slope microbial mud mound core in OCS-A 0336 (C3)

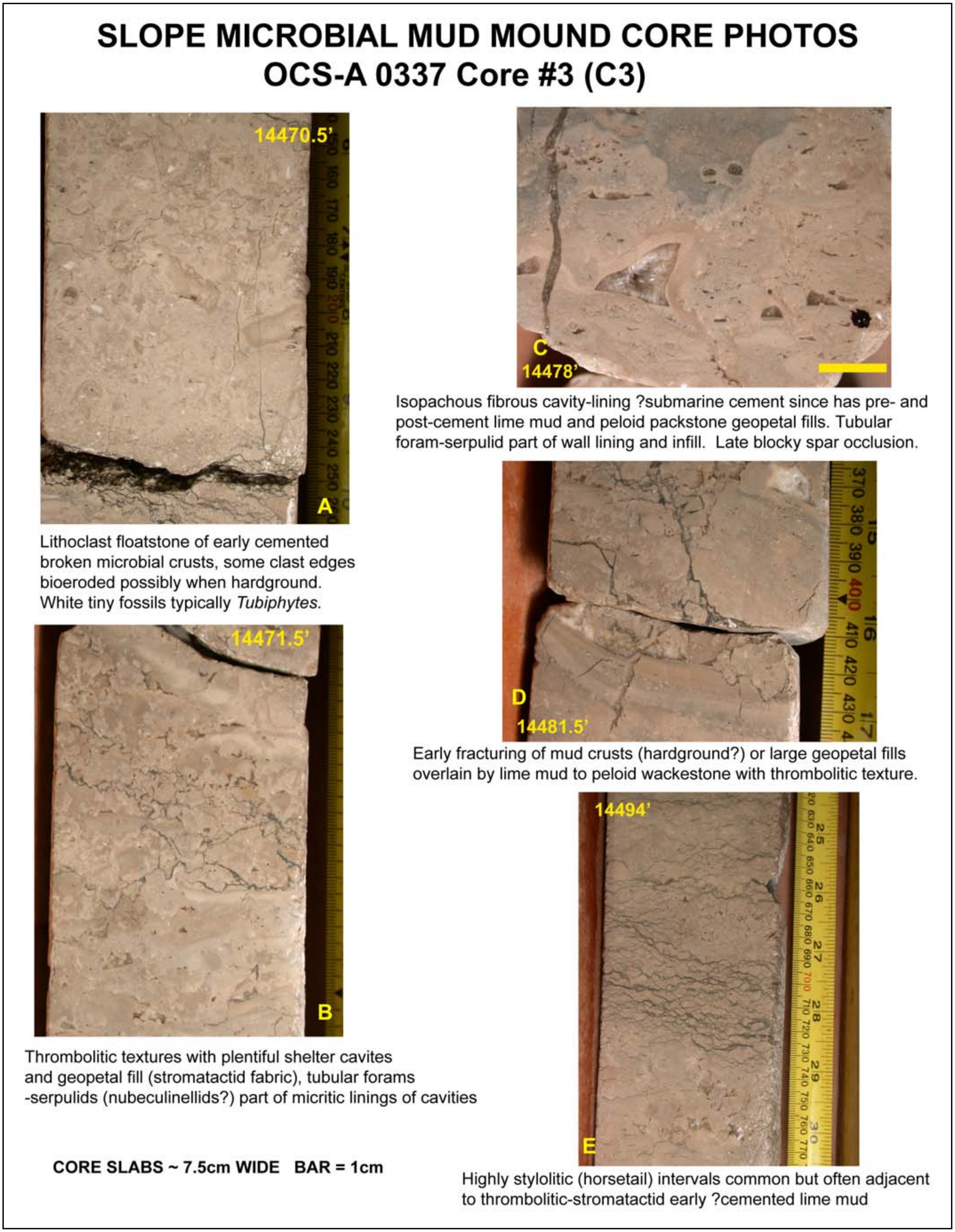


**Figure 11.** Core photos of slope microbial mud mound in OCS-A 0336 (C3)

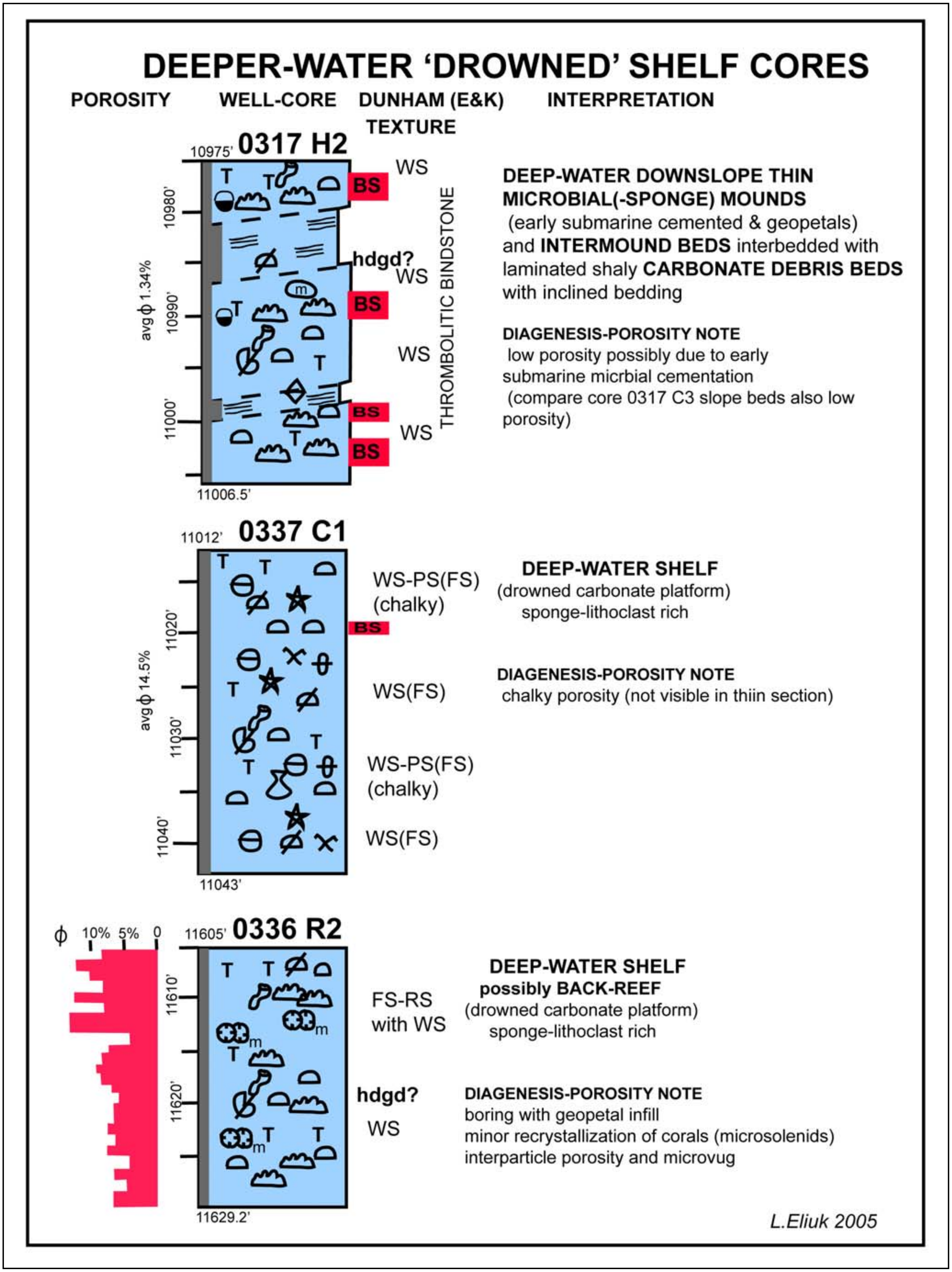


**Figure 12**. Schematic of deeper-water 'drowned' shelf cores in OCS-A 0317 (H2), OCS-A 0337 (C1), and OCS-A 0336 (R2).

# DEEPER-WATER 'DROWNED' SHELF CORES

## OCS-A 0317 Core #2 (H2), OCS-A 0337 Core #1 (C1), OCS-A 336 core #2 (R2)


**A- *in situ* lithistid sponge with geopetal infill in central cavity and overgrown by coralline sponge (?stromatoporoid) in skeletal-lithoclast float/wackestone**


**D- inclined argillaceous laminated debris beds with angular lithoclasts & skeletal fragments. White specks tubular forams-*Tubiphytes***


**B- microsolenid coral clast and sponge-microbial-oncolitic consortia in skeletal fragment-*Tubiphytes* wackestone**


**E- inclined stylolitic mudstone layer = ?hardground overlain by lithistid sponge fragments (and ?*in situ* since central cavity present) in *Tubiphytes*-foram wackestone**


**C- irregular bioeroded fragment of biolithite consortia of corals-lithistid sponges-foram (*Lithocodium*?)-microbialite in skeletal-fragmental floatstone-*Tubiphytes* wackestone**


**F- *Tubiphytes*-rich microbialite? with complex cavity system partly geopetally infilled by lime mud. System now completely cemented by clear calcite spar**

**Figure 13**. Core photos of deeper-water 'drowned' shelf cores in OCS-A 0317 (H2), OCS-A 0337 (C1), and OCS-A 0336 (R2).

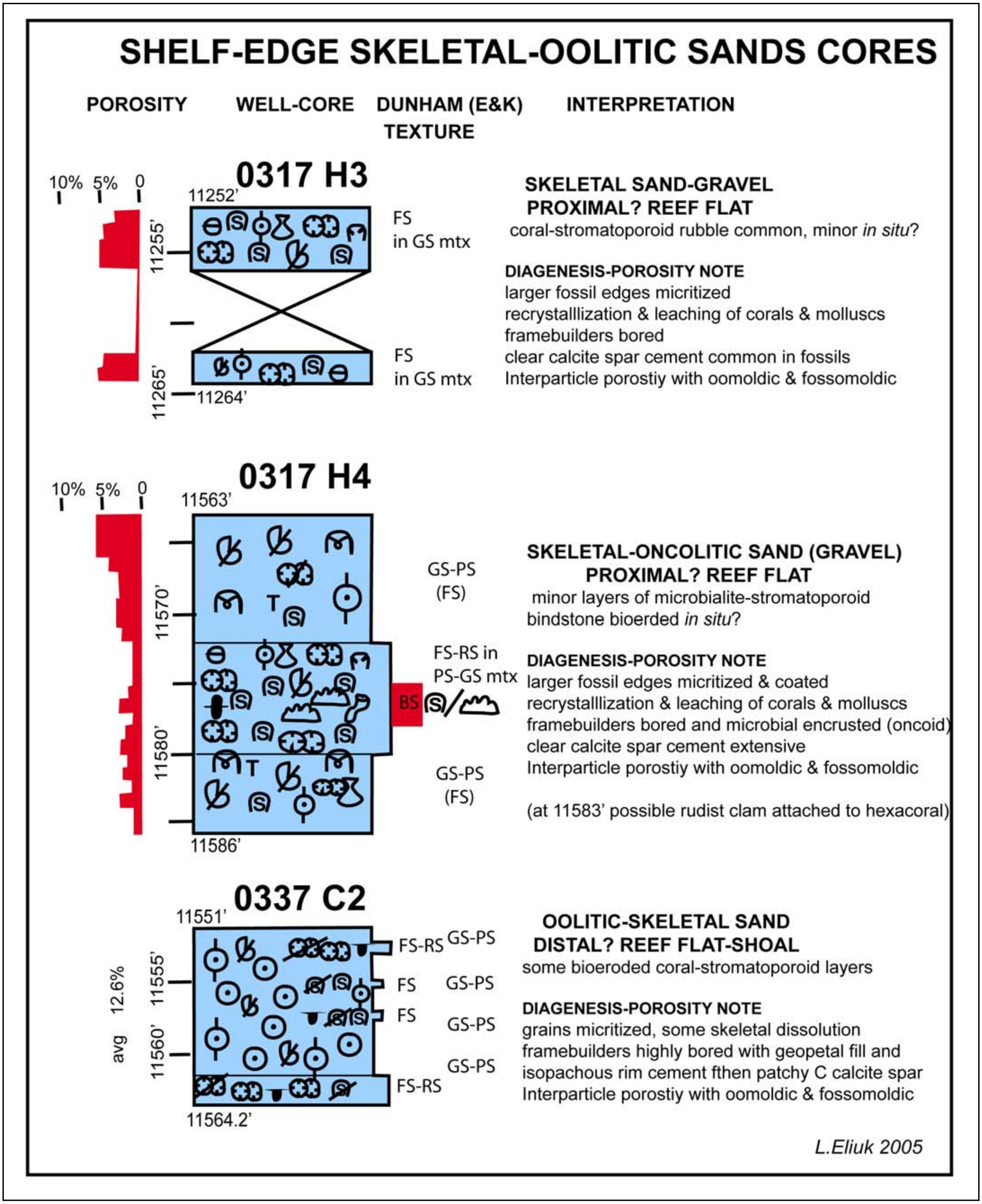


**Figure 14**. Schematic of shelf-edge oolitic-skeletal ‘sands’ cores in OCS-A 0317 (H3, H4)), OCS-A 0337 (C2).

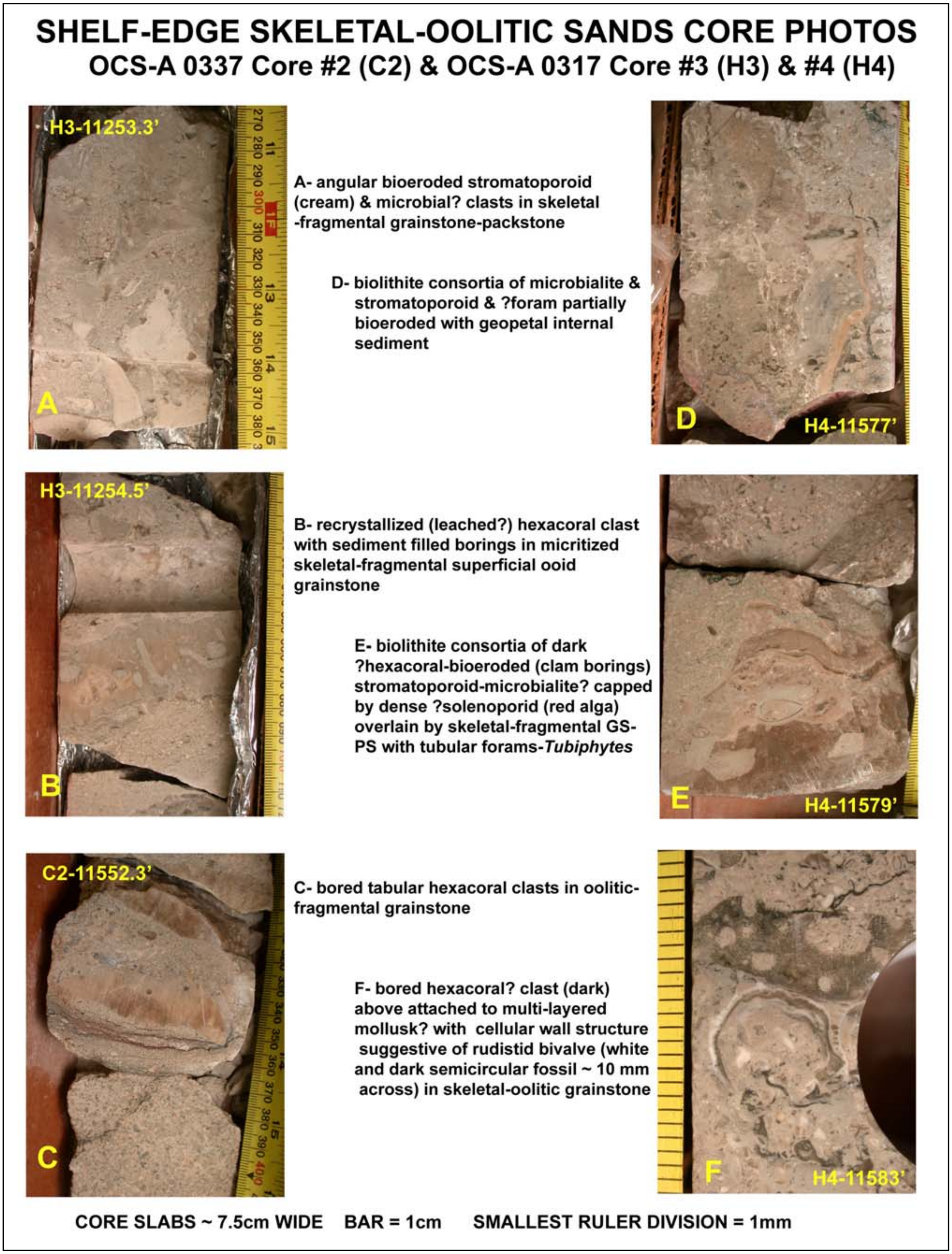


**Figure 15**. Core photos of shelf-edge oolitic-skeletal 'sands' cores in OCS-A 0317 (H3, H4)), OCS-A 0337 (C2).

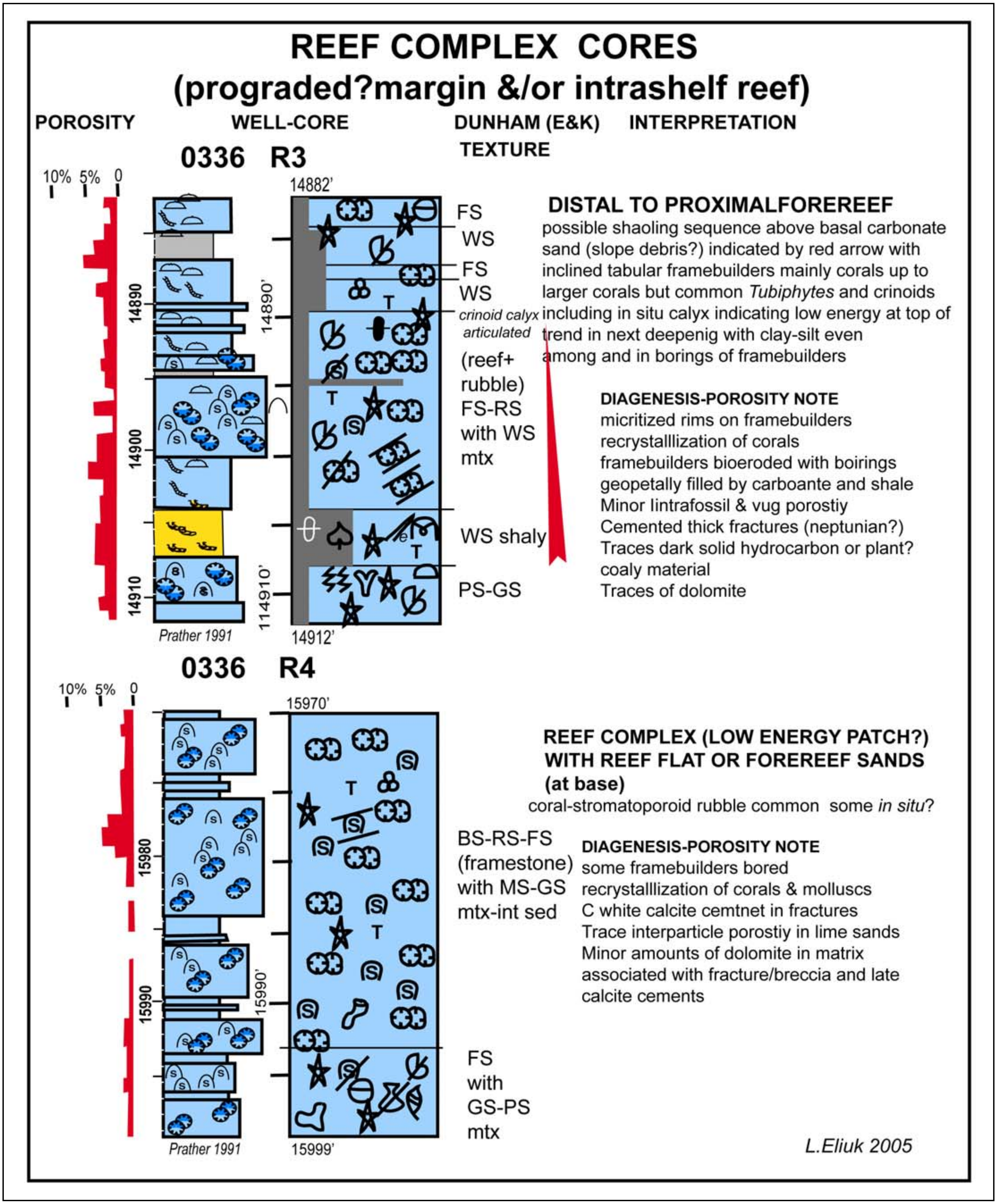


**Figure 16**. Schematic of prograding or intrashelf reef complex cores in OCS-A 0336 (R3, R4).


**Figure 17**. Core photos of prograding or intrashelf reef complex cores in OCS-A 0336 (R3, R4).

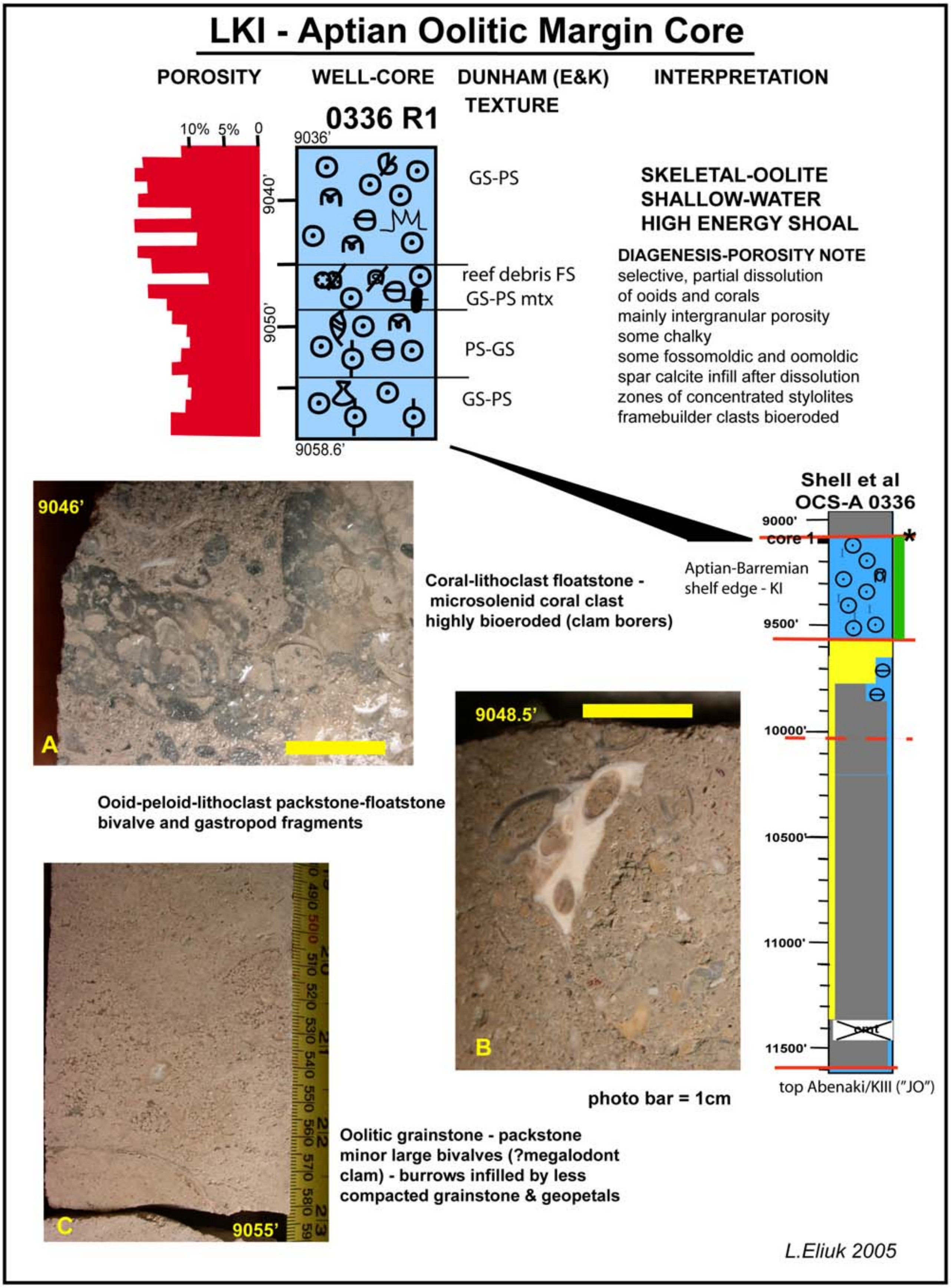


**Figure 18**. Schematic of Aptian oolitic margin core in OCS-A 0336 (R1).

## DISCUSSION AND CONCLUSIONS

At present Baltimore Canyon Trough and Nova Scotia Basin are the only two areas of the western North Atlantic Jurassic carbonate platforms that have exploration drilling at the margin. They have many similarities that may allow depositional models and biological depth zonations to be proposed for Jurassic-Neocomian Atlantic margin carbonates. As well they document regional Berriasian-Valanginian drowning events. They show the importance of being at the margin for carbonate reservoir development. They document the widespread development of three buildup types - hexacoral-coralline sponge (stromatoporoid-chaetetid) reefs, microbial (thrombolitic-stromatactis-algal?) mud mounds and lithistid sponge reef mounds – apparently in increasingly greater water depths from shallow shelf to slope to drowned shelf. Caution is required in interpreting the distribution of microbial buildups since they have a very great variability and depth range (Mancini et al. 2004). The two basins show the importance of the interplay between clastics and carbonates. Either over time, aiding the early carbonate margin progradation over inferred siliciclastic clinoforms as in Baltimore Canyon (see Fig 13 in Meyer 1989) or in different areas along the margin at the same time as in Nova Scotia (see Fig. 5 in Eliuk 1978 and Fig. 3 in Eliuk 1998). In Baltimore Canyon the change from pure carbonates at the margin westward to mainly siliciclastics in the shelf interior is more rapid. In contrast it is more gradual in Nova Scotia southwest of the Sable Island paleodelta. But near the Late Jurassic paleodelta there is a greater interbedding of thin oolitic-skeletal carbonates and various siliciclastics distributed in a progradational manner with a true ramp morphology (Eliuk 1978, Ellis et al. 1985).

They also have differences, particularly in amount of skeletal and grain-supported fabrics, in siliciclastic to carbonate facies gradients across the shelf, in rates of subsidence, and in greater amount of progradation in the Middle and early Late Jurassic. These four factors are much greater in Baltimore Canyon. The Baltimore Canyon wells in general sample much more carbonate-sand-rich beds. Whereas the Nova Scotia margin wells sample muddier but much more reef framebuilder-rich beds. In fact to see the full spectrum of Jurassic- Cretaceous reef and near-reef facies, cores from both Canada and the United States are needed. Happily the re-display by Eliuk of Wierzbicki et al. (2005, CD – CSPG core conference and again in 2008) allows the comparison. While the basins have some major difference, these biofacies differences may simply indicate a "sampling" bias; possibly shallow-water Jurassic-early Cretaceous reefs simply grew in slightly deeper water with the skeletal-oolitic sands occupying the shallowest margin edge. The Baltimore Canyon wells are behind the very edge of the margin and get reef-flat sands more commonly. Most of the Canadian margin wells are located nearer the steep margin between the "double-flexure" or slightly "down-ramp" of a distally-steepened margin (Eliuk 1978, Wierzbicki et al 2005). When the upper flexure more proximal portion of the "platform-ramp" margin is sampled in Nova Scotia as in Panuke F-09 there are very little reefal beds and a lot of oolitic grainstones even though the well is less than 2 km from the edge. Note the Abenaki platform "distally steepened ramp" is definitely a platform margin with steep slopes into oceanic depths. When reefal beds were cored in Baltimore Canyon in OCS-A 0336 (R3 and R4) the reefal beds were much muddier both from in lime and clay mud, similar to many of the reefal cores in the Nova Scotia Abenaki. Unlike modern warm-shallow-water coral reefs, these mid-Mesozoic reefs apparently could live in shalier and more nutrient-rich waters.

Differences are also seen in diagenetic contrasts with degree of dolomitization being significant. The Nova Scotia Abenaki margin has much greater amounts of dolomite but Baltimore Canyon has greater amounts of primary limestone porosity. Significantly, there is shelf-margin faulting in the stationary Nova Scotia margin in the Demascota-Panuke-Cohasset trend and on the western LaHave shelf with associated porous dolomite (see especially Wierzbicki et al. 2006 for a Panuke porosity model involving faulting and hydrothermal dolomitization and Eliuk 2004 for a bit of history). In Baltimore Canyon, the ultimate shelf edge results from progradation and major faulting occurs not at the margin but westward within the shelf interior. Dolomite though uncommon does occur in some more interior wells such as Shell et al. OCS-A 0336, Tenneco Spitfire OCS-A 131 and Tenneco 0036 #2 with its gas show. Different amounts of overburden may also account for the limestone porosity differences. Particularly off Nova Scotia where early burial under the contemporaneous and younger Sable Island paleodelta depocentre appears to have resulted in much reduced reservoir development. Due to the great water depths over the Baltimore Canyon margin the effective burial depth is much less and porosity is higher. When that burial is increased as below the thicker mid-Cretaceous deltaic sediments of the OCS-A 0336 well, the porosity in the reefal beds near TD at 16000 feet is very poor.

Over the years, wells from the these two west Atlantic basins have helped in understanding each other better. The best depositional and diagenetic models will integrate both data sets.


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## REFERENCES


Crevello, P.D. and Harris, P.M. 1984. Depositional models for Jurassic reefal buildups. Gulf Coast SEPM 3rd Research Conference, p. 57-102.
.

Eliuk, L.S. 1978. The Abenaki Formation, Nova Scotia Shelf, Canada - a depositional and diagenetic model for a Mesozoic carbonate platform, Bulletin Canadian Petroleum Geology, v. 26, p. 424-514.

Eliuk, L.S., 1981, Abenaki update: variations along a Mesozoic carbonate shelf, Nova Scotia Shelf, Canada: Canadian Society of Petroleum Geology. Annual core and field sample conference, January 1981, p. 15-19.

Eliuk, L.S. 1991. Platform carbonate termination and sponge reefs: the western Atlantic Mesozoic margin example. In: Bosselini, a., Brandner, R. Flugel, E., Purser, B., Schlager, W., Rucker, m. and Zenger, D. (eds.) Dolomieu Conference on Carbonate Platforms and Dolomitization, The Dolomites, Italy, P. 69-70

Eliuk, L.S. 1998. Big bivalves, algae and the nutrient poisoning of reefs: a tabulation with examples from the Devonian and Jurassic of Canada. In: Johnston, P.A. and Haggart, J.W. (ed.) Bivalves: An eon of Evolution; University of Calgary Press, p.157-184

Eliuk, L.S. 2004. History of the practical application of a failed? dolomite model (Mixing Zone) to the "Demascota Dolomite Beds" of the Abenaki Formation, Nova Scotia offshore Late Jurassic paleocontinental shelf carbonate margin. In: Dolomites – The Spectrum: mechanisms, models, reservoir development, CSPG Seminar and Core Conference, January 13-15th (15 pages on CSPG CD).

Eliuk, L.S., Cearley, S.C. and Levesque R. 1986. West Atlantic Mesozoic carbonates: comparison of Baltimore Canyon and Offshore Nova Scotian Basins. American Association of Petroleum Geologists Bulletin, v. 70, p.586-587 (abstract).

Eliuk, L. and Levesque, R. 1989 Earliest Cretaceous sponge reef mound Nova Scotia shelf (Shell DemascotaG-32). In: Geldsetzer, H.H.J., James, N.P. and Tebbutt, G.E. (eds.). Reefs, Canada and Adjacent Areas. Canadian Society of Petroleum Geologists, Memoir 13, p.713-720

Eliuk, L.S. and Prather, B.E. 2005. Baltimore Canyon Trough Mesozoic Carbonate Margin Cores, Offshore USA Atlantic. Abstract and core conference article – CSPG-AAPG Convention June core conference in Calgary AB (31 pages on CD).

Ellis, P.M., Crevello, P.D. and Eliuk, L.S. 1985. Upper Jurassic and Lower Cretaceous deep-water buildups, Abenaki Formation, Nova Scotia Shelf. In: Crevello, P.D. and Harris, P.M. (eds.), Deep-water Carbonates: A Core Workshop, SEPM Core Workshop No. 6, p. 212-248

Embry III, A.F., and Klovan, J.E., 1971, A Late Devonian reef tract on northwestern Banks Island, Northwest Territories. Bulletin Canadian Petroleum Geology., v. 19, p. 730-781.

Erlich, R.N., Barrett, S.F. and Guo Bai Ju. 1990. Seismic and geologic characteristics of drowning events on carbonate platforms. American Association of Petroleum Geologists Bulletin, v. 74, p. 1523-1537.

Erlich, R.N., Longo, Jr., A.P. and Hyare, S. 1993. Response of carbonate platform margins to drowning: evidence of environmental collapse. In: Loucks, R.G. and Sarg, J.F. (ed.), Carbonate Sequence Stratigraphy – Recent Developments and Applications, American Association of Petroleum Geologists, Memoir 57, p. 241-286

Flugel, E. and Steiger, T. 1981. An Upper Jurassic sponge-algal buildup from the northern Frankenalb, West Germany. In: Toomey, D.F. (ed.) European Reef Models, Society of Economic Paleontologists and Mineralogists, Special Publication 30, p. 371-397.

Insalaco, E. 1996. Upper Jurassic microsolenid biostromes of northern and central Europe: facies and depositional environment. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 121, p. 169-194.

Jansa, L.F., Pratt, B.R. and Dromart, G. 1988, Deep water thrombolite mounds from the Upper Jurassic of offshore Nova Scotia In: Geldsetzer, H.H.J., James, N.P. and Tebbutt, G.E. (eds.), Reefs - Canada and Adjacent Areas. Canadian Society of Petroleum Geologists Memoir 13, p.725-735

Karlo, J.F. 1986. Results of exploration in Mesozoic shelf-edge carbonates, Baltimore Canyon Basin. American Association of Petroleum Geologists Bulletin, v. 70, 605-606 (abstract).

Leinfelder, R.R., 1994. Distribution of Jurassic reef types: a mirror of structural and environmental changes during breakup of Pangea. In: Embry, A.F., Beauchamp, B. and Glass, D.F. (ed.), Pangea: Global Environments and Resources, Canadian Society of Petroleum Geologists Memoir 17, p. 677-700.

Leinfelder, R.R. Schmid, D.U. Nose, M and Werner, W. 2002. Jurassic reef patterns – the expression of a changing globe. In: Kiessling, W., Flugel, E. and Golonka, J.(Eds.), Phanerozoic Reef Patterns, SEPM Special Publication No. 72, p. 465-520.

Libby-French, J. 1984. Stratigraphic framework and petroleum potential of northeastern Baltimore Canyon Trough, mid-Atlantic outer continental shelf. American Association of Petroleum Geologists Bulletin, v. 68, p. 50-73.

Mancini, E.A., Llinas, J.C., Parcell, W.C., Aurell, M., Badenas, B., Leinfelder, R.R. and Benson, D.J. 2004. Upper Jurassic thrombolite reservoir play, northeastern Gulf of Mexico. American Association of Petroleum Geologists Bulletin, v. 88, p. 1573-1602.

Meyer, F.O. 1986. Facies specificity of megaporosity in Mesozoic shelf-edge carbonates from the Baltimore Canyon Basin. American Association of Petroleum Geologists Bulletin, v. 70, p. 621 (abstract).

Meyer, F.O. 1988. Siliciclastic influenced development of the Mesozoic Wilmington Platform, Western Atlantic In: Harris, P.M. and Crevello. P.D. (eds.), Controls on Carbonate Platforms. Society of Economic Paleontologists and Mineralogists Special Paper No. 40, p. 213-232.

Minerals Management Services. 2000. Assessment of Conventionally Recoverable Hydrocarbon Reserves of the Gulf of Mexico and Atlantic Outer Continental Shelf as of January 1, 1995. (Available as a PDF at www.gomr.mms.gov.)

Minerals Management Services. 2003. Assessment of Technical Recoverable Oil and Gas Resources of the Nation's Outer Continental Shelf, 2003 Update. (Available as a PDF at www.gomr.mms.gov)

Poag, C.W. 1991. Rise and demise of the Bahama-Grand Banks gigaplatform, northern margin of the Jurassic proto-Atlantic seaway. Marine Geology, v. 102, p. 63-139.

Poag, C.W., Swift, B.A., Schlee, J.S., Ball, M.M. and Sheetz, L.L. 1990. Early Cretaceous shelf-edge deltas of the Baltimore Canyon Trough: Principal sources for sediment gravity deposits of the northern Hatteras Basin. Geology, v. 18, p. 149-152.

Prather, B.E. 1991. Petroleum geology of the Upper Jurassic and Lower Cretaceous, Baltimore Canyon Trough, western North Atlantic Ocean. American Association of Petroleum Geologists Bulletin, v. 72, p. 258-277.

Ringer, E.R. and Patten, H.L. 1986. Biostratigraphy and depositional environments of Late Jurassic and Early Cretaceous carbonate sediments in Baltimore Canyon Basin. American Association of Petroleum Geologists Bulletin, v. 70, p. 639-640 (abstract).

Wierzbicki, R., Dravis, J.J., Al-Aasm, I., and Harland, N. 2006. Burial dolomitization and dissolution of Upper Jurassic Abenaki platform carbonates, Deep Panuke reservoir, Nova Scotia, Canada. American Association of Petroleum Geologists Bulletin, v. 90, p. 1843-1861.

Wierzbicki, R., Harland, N. and Eliuk, L. 2002. Deep Panuke and Demascota core from the Jurassic Abenaki Formation, Nova Scotia – Facies model, Deep Panuke, Abenaki Formation. Canadian Society of Petroleum Geologists 75$^{th}$ Diamond Jubilee Convention Core Convention Abstracts including extended abstracts, p.71-94. (plus Appendix by Eliuk and Pemberton, also on CD as PDF in color).

Wierzbicki, R. Gillen, K., Ackermann, R., Harland, N., Eliuk, L. and Dravis, J. 2005, Interpretation of a fractured dolomite core: Margaree F-70, Deep Panuke, nova Scotia, Canada. Canadian Society of Petroleum Geologists Annual Core Conference in conjunction with AAPG Annual Convention in Calgary.(extended abstract-article in this CSPG CD)