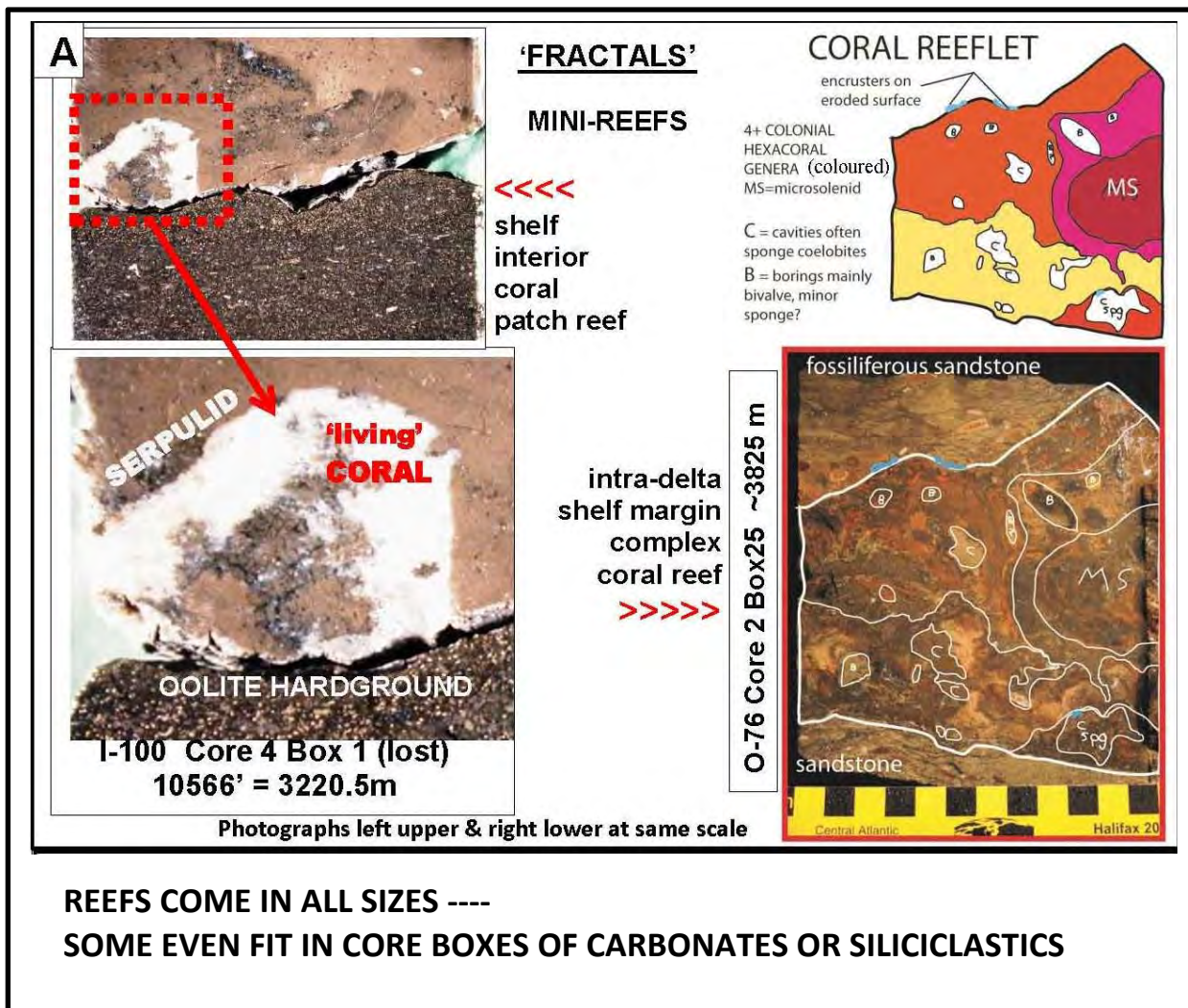


CONJUGATE MARGINS CONFERENCE 2018

Celebrating 10 years of the CMC: Pushing the Boundaries of Knowledge



Core Workshop

Canada-Nova Scotia Offshore Petroleum Board
Geoscience Research Centre, Dartmouth, Nova Scotia
August 23, 2018

ISBN: 0-9810595-11



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Editors: David E. Brown & Leslie S. Eliuk

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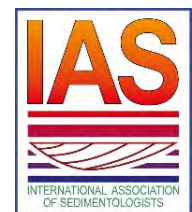
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Schedule of Events

Saturday, August 18

- Field Trip 1: *Petroleum Systems of Atlantic Canada Basins* Day 1 of 2 Joggins area, Nova Scotia
- Short Course 1: *Salt Tectonics of Conjugate Margins* (Day 1) 0900-1700 LSC, Milligan Rm. LSC 8007, 8th Floor

Sunday, August 19

- Registration Pick-Up 1000-1900 SUB Bldg., Main Floor Lobby
- Field Trip 1: *Petroleum Systems of Atlantic Canada Basins* Day 2 of 2 Five Islands area, Nova Scotia
- Field Trip 2: *Cretaceous Chaswood Formation* Day 1 of 1 Hants County / Halifax area, Nova Scotia
- Short Course 1: *Salt Tectonics of Conjugate Margins* (Day 2) 0900-1700 LSC, Milligan Rm. LSC 8007, 8th Floor
- Poster Set-up 1330-1700 SUB, McInnes Rm., 2nd Floor
- Welcoming Reception (posters & booth displays open) 1700-2100 SUB, McInnes Rm., 2nd Floor

Monday, August 20

- Registration Pick-Up 0700-1900 SUB Bldg., Main Floor Lobby
- Oral: *Geodynamics Rift to Drift* - 10800-1205 Marion McCain Bldg., Scotiabank Auditorium
- LUNCH 1205-1300 SUB, McInnes Rm., 2nd Floor
- Oral: *Geodynamics Rift to Drift* - 21305-1715 Marion McCain Bldg., Scotiabank Auditorium
- Poster & Corporate Displays, and G&G Data Rooms All Day SUB, McInnes Rm., 2nd Floor

Tuesday, August 21

- Oral: *Geochemistry & Petroleum Systems* 10800-1210 Marion McCain Bldg., Scotiabank Auditorium
- Oral: *Stratigraphy & Sedimentation* 10800-1210 Marion McCain Bldg., Ondaatje Hall
- LUNCH 1210-1325 SUB, McInnes Rm., 2nd Floor
- Oral: *Geochemistry & Petroleum Systems* 21330-1715 Marion McCain Bldg., Scotiabank Auditorium
- Oral: *Stratigraphy & Sedimentation* 21330-1715 Marion McCain Bldg., Ondaatje Hall
- Poster & Corporate Displays, and G&G Data Rooms All Day SUB, McInnes Rm., 2nd Floor
- Conference Banquet 1900-2100 Murphy's on the Waterfront, Cable Wharf

Wednesday, August 22

- Oral: *Exploration Thinking for Atlantic Conjugate Margins* 10800-1210 Marion McCain Bldg., Ondaatje Hall
- Oral: *Regional Geology* 10800-1210 Marion McCain Bldg., Scotiabank Auditorium
- LUNCH 1210-1325 SUB, McInnes Rm., 2nd Floor
- Oral: *Exploration Thinking for Atlantic Conjugate Margins* 21330-1715 Marion McCain Bldg., Ondaatje Hall
- Oral: *Regional Geology* 21330-1650 Marion McCain Bldg., Scotiabank Auditorium
- Poster & Corporate Displays, and G&G Data Rooms All Day SUB, McInnes Rm., 2nd Floor
- Short Course 2: *Salt Tectonics Cape Breton, Nova Scotia* 1700 Depart. SUB – Drive Halifax to Cape Breton, NS
- Hand-over to 2020 Conference Team 1715-1730 Marion McCain Bldg., Ondaatje Hall
- Farewell Gathering 1730-1900 SUB, McInnes Rm., 2nd Floor
- Poster Break-down 1900-1930 SUB, McInnes Rm., 2nd Floor

Thursday, August 23

- Workshop 1: *Scotian Basin Reservoir Core Workshop* 0900-1600 CNSOPB - GRC, Dartmouth, NS

NOTES: Registrants for the two pre-meeting Field Trips 1 and 2, Short Course 1, and the post-meeting Core Workshop will have registration packages provided directly to them prior to their start.

Each morning and afternoon oral session has a 25-minute refreshment break mid-way through the session.

The recording, taping, and/or photographing of oral and poster presentations is strictly prohibited.

ABBREVIATIONS: CNSOPB - GRCCanada-Nova Scotia Offshore Petroleum Board - Geoscience Research Centre (Workshop 2).

LSC Dalhousie University Life Sciences Centre (Workshop 1).

SUB Dalhousie University Student Union Building (registration, receptions, field trip departures and returns, poster and corporate displays, G&G data rooms, lunches, refreshment breaks).





Core Presentations

These following presentations are arranged in stratigraphic order, i.e. youngest to oldest.

1. Late Cretaceous Wyandot Formation chalk properties – Eagle D-21 Core Study

Leslie Eliuk, Yawooz Kettanah, and Grant D. Wach

2. Stratigraphy and Sedimentology of the Lower Missisauga and Mic Mac formations in the Migrant expansion trend, Sable Subbasin, Offshore Nova Scotia.

Kenneth T. Martyns-Yellowe, Grant D. Wach, and Neil Watson

3. Baltimore Canyon Trough Mesozoic carbonate margin cores, offshore USA Atlantic

Leslie Eliuk and Brad Prather

4. Thin carbonates in thick siliciclastic successions: a useful key to depositional environments, sequence breaks and geological history – two core examples (South Desbarres O-76 and West Venture C-62 #9 Limestone) from the Jurassic-Cretaceous offshore Nova Scotia.

Leslie Eliuk

5. A continental-scale delta's effect on the north end of a Jurassic-Cretaceous gigaplatform: The Abenaki carbonate-Sable Delta study a decade or so later, offshore Nova Scotia.

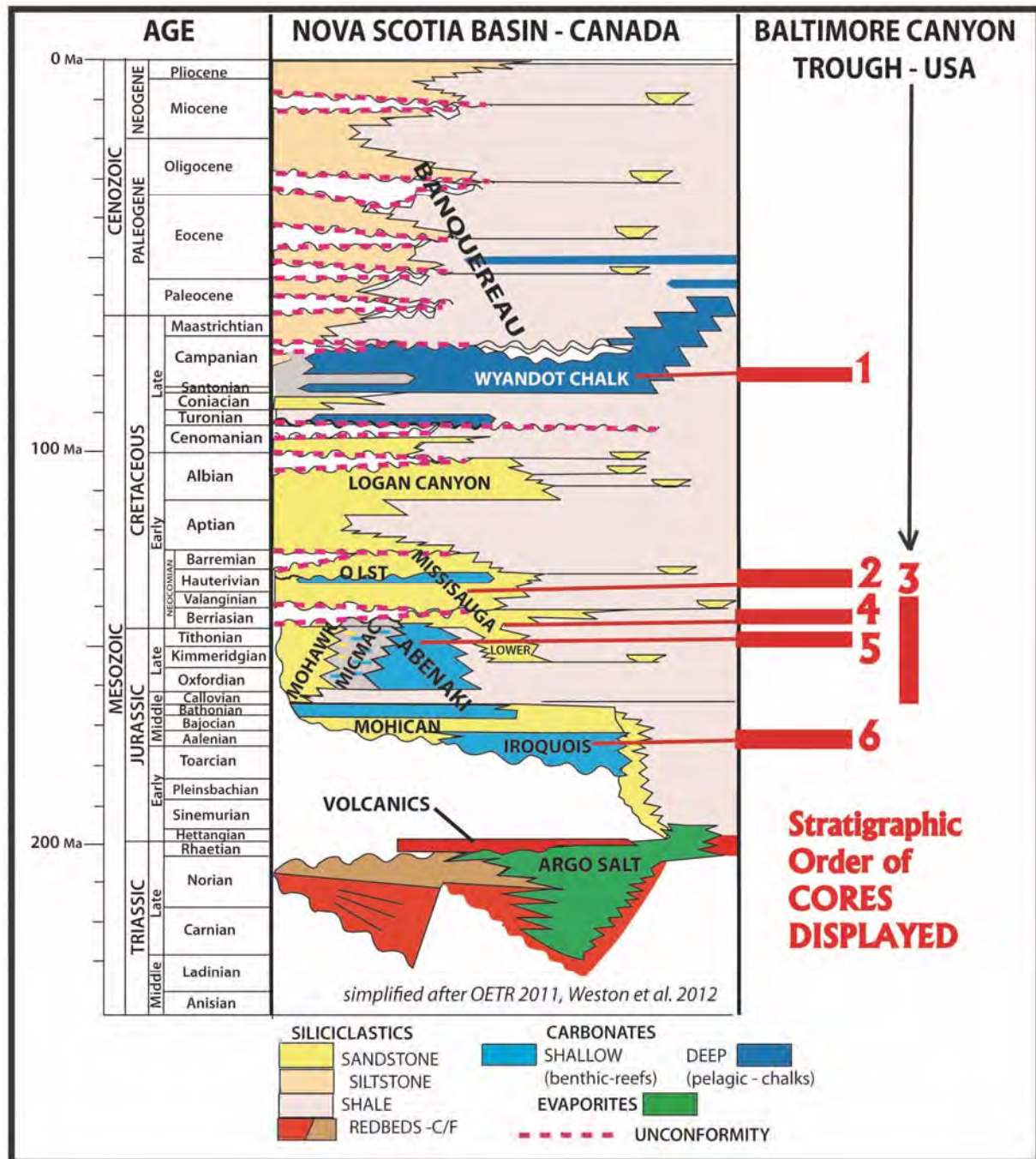
Leslie Eliuk

6. Jurassic environments (Iroquois Formation) of the Scotian Basin, Nova Scotia, Canada

Ricardo L. Silva, Maya Soukup, and Grant D. Wach

A THANK YOU

We hardily thank all the staff at the CNSOPB Geoscience Research Centre for making their facility a great venue for this core workshop and particularly Debra Wheeler and Anita Nicoll who handled the core and cuttings for our displays.



Simplified Nova Scotia offshore stratigraphic chart with location of cores displayed.



LATE CRETACEOUS WYANDOT FORMATION CHALK PROPERTIES – EAGLE D-21 CORE STUDY

Leslie Eliuk¹, Yawooz Kettanah² and Grant D. Wach³

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1. Summary Overview

The regional findings presented below are based on the interpretation of literature and well histories. References omitted for reading clarity but occur in References at end of text and on figures.

A. Deposition of the Wyandot Formation chalk resulted from condensed long-continued slow pelagic sedimentation (Coniacian-Maastrichtian circa 20 Ma) of nannofossils and microfossils (algal coccolithophorids and foraminifera).

B. The region where the Eagle D-21 well was drilled is distal chalk (Glenelg to Primrose trend) is generally far from siliciclastic input and dilution so is very clean even though the upper Wyandot Formation is part of a large-scale mixed siliciclastic-carbonate system. It occurs within a polygonal fault system well away from other updip areas of seismically-identified allochthonous re-sedimentation due to mass wastage.

C. The Eagle structure is a faulted rollover anticline with the Wyandot under relatively shallow burial (1.6-1.8 km). It likely lacks freshwater incursion and with the presence of hydrocarbons have preserved high porosities: 18.5-35.8 % average 28.1 % porosity, and 0.21-1.4 md average 0.56 md permeability (non-fractured samples in Eagle D-21 core).

D. The North Sea (Ekofisk area) may be a well-used but inappropriate analogue notwithstanding the many similarities of same-aged pelagic carbonate deposition. But, major differences compromising reservoir comparison include (Eagle-Primrose vs *North Sea Ekofisk* (in italics)).

- Oceanic shelf margin with regional siliciclastic input vs *an enclosed shelf sea lacking significant siliciclastics (but finer nanno-microfossils and siliceous insoluble residues present in Paleocene).*
- Comparatively thin (+/- 200 m) on shelf/slope vs *thick to 1.5 km in basin-centre trough.*
- Autochthonous sedimentation cored (updip are re-sedimented areas of mass wastage that unfortunately may mix in clays from above the Wyandot) vs *allochthonous re-sedimentation. The latter is common due to basin centre location (disputably considered a key to better reservoir due to supposedly rapid sedimentation that winnows/cleans chalk and perhaps lessens seafloor cementation as opposed to the effect of higher insoluble residue causing greater pressure solution-poorer reservoirs considered more important by others – see 2d below).*
- Shallow vs *deep* burial
- Normally pressured vs *overpressured in subsiding graben centre that may have taken shallow early hydrocarbon-charged reservoir to greater depths preserving porosity.*



A possibly more appropriate analogue worth investigation is the Dan Oil Field area in Danish waters on the southern North Sea graben flanks at 1800 m depth of burial.

2. Summary Results of Core Study

A. The Eagle D-21 cores from the upper third of the Wyandot Formation show only one facies - massive white highly bioturbated porous chalk (porosity = 18.5-34.8 % average 28.1% and permeability = 0.21-1.4 md average 0.56 md excluding fractured plugs). There is only minor stylolitization observed except when localized in a possibly cyclic diagenetic subfacies. This pressure-solution concentrated laminated dark limestone subfacies with residue up to 6 cm thick (possibly unique and termed “stylo-laminites”) has adjacent porosity reduced to about 14% in close-proximity chalks due perhaps due to local re-precipitated cements of pressure-solution dissolved calcite. Because these stylo-laminites mainly occur in the upper part of the D-21 cores, there is actually a reversal of the expected deterioration with depth and most of the best porosity-permeability is at the base of the 24 m of core. Yet clean chalk between the stylo-laminites can have very high values giving local variability.

There is no evidence for allochthonous re-sedimentation nor early-cemented hardgrounds, but there is preservation of whole coccolithophores and some instances of burrow-associated better porosity. At SEM-scale, tiny calcite cement rhombs of various sizes encrust micro- and nannofossils and degraded coccoliths occur, but rarely intact coccolithophorids. Undoubtedly, this is the result of chemical pressure solution that diagenetically reduces porosity-permeability. But, porosity is so high that visual correlation of cements with porosity measurements is not convincing and also may be complicated by micro-scale variability in SEM examination.

B. Cores (#5 and top #6) from the Primrose A-41 well at the base of the Wyandot were examined so that dark argillaceous to marly facies could be included. Both Eagle D-21 (in very minor amounts) and A-41 (in higher amounts) contain clays - kaolinite, illite, montmorillonite, and mixed mica-smectite layers (rectorite) - and other insoluble residues such as quartz, pyrite and marcasite. A-41 also contains sometimes high-amounts of glauconite (over 10%). Stylolites and flaser solution zones are much more prevalent in A-41.

C. The Eagle D-21 core does not show intense or even very obvious post-lithification jointing or fracturing but one of the several broken intervals had steps on a broken surface with slight grey staining so fracturing may be cryptic. In contrast, all cores in Primrose A-41 showed common slickensiding failure and fracture offsets. Stylolite zones show some opening along their paths and occasional microfractures that might act as channels for fluids.

D. Because of the relatively shallow burial and therefore good porosity of the Wyandot near Eagle-Primrose, the controls on deep burial preservation, as applied to the Ekofisk Chalk (see 1D above), are not that important but may have importance for reservoir variability and deliverability. Wyandot porosities from core averages (Eagle and Primrose) plotted on published porosity-depth graphs and from core samples adjacent to stylolitic concentrations, particularly as associated with greater insoluble residue zones, show a greater porosity in cleaner (and less stylo-laminated) chalks and reduced porosity in dark more argillaceous chalk or adjacent to highly stylolitized intervals. Better permeability varies directly with better porosity (some literature states that argillaceous content and pressure solution effects deteriorate reservoir quality by affecting permeability rather than porosity). Clean chalk versus argillaceous chalk or residue-rich stylolitized intervals may be more important



as a primary early control on porosity-permeability than the North Sea Central Graben deposition model of allochthonous/re-sedimented (good) versus *in situ*/autochthonous (not so good).

Acknowledgements

This study was completed in 2009 for Ammonite Nova Scotia at the request of Bob Merrill and Skip Hobbs whom we thank for support and encouragement. That report was submitted to the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB). It benefitted greatly from published and personal communications by Prof. Andrew MacRae (St. Mary's University, Halifax NS), Dr. Hans Wielens (deceased - former Geological Survey of Canada, Dartmouth NS) and Brenton M. Smith (Canada-Nova Scotia Offshore Petroleum Board, Halifax, NS) particularly for regional Wyandot and Primrose area core and seismic information.

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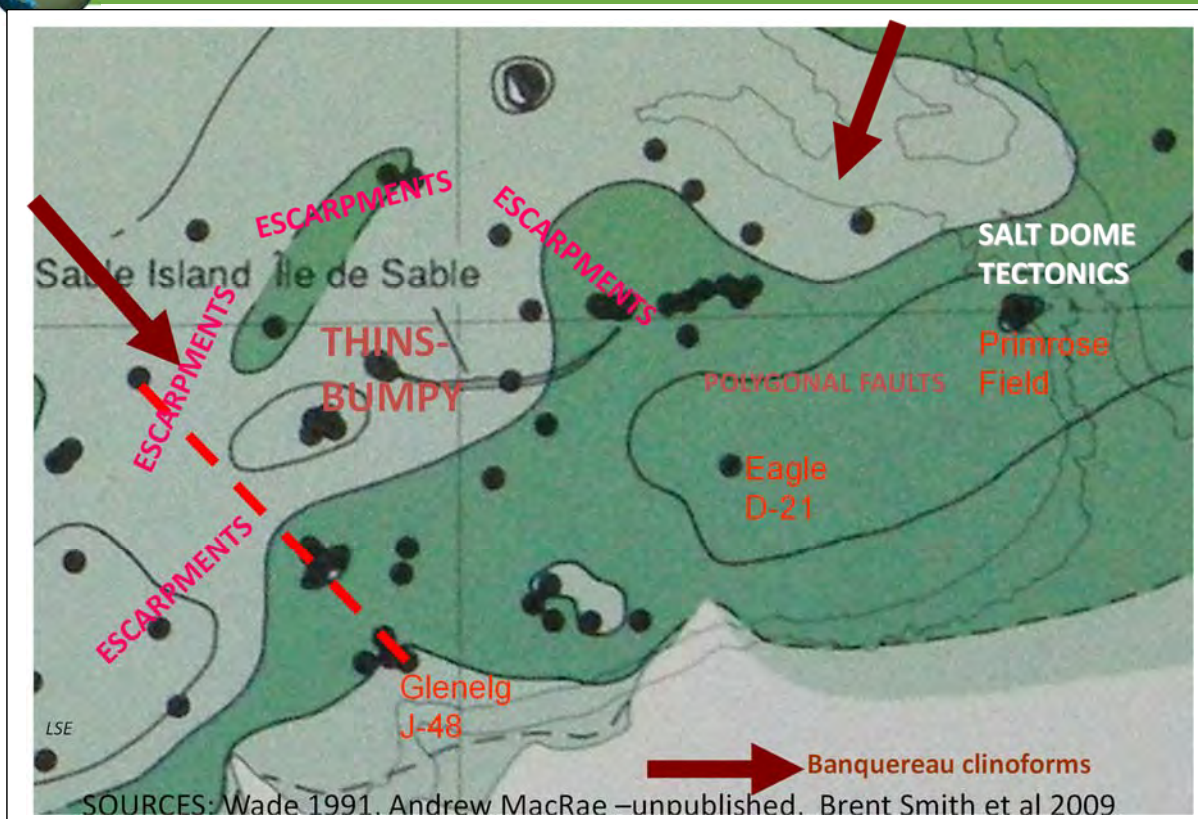


Figure 1. Location Map Wyandot Formation chalk isopach (From Eliuk and Wach 2010 modified from map in Wade 1991 with additional information as labelled). Primrose Field discovered in 1972 is stranded in the Gully Marine Protected Area with hydrocarbons reservoirised in chalk on a salt dome. Eagle D-21 had significant gas shows on test. Much of the Wyandot chalk is the downdip correlative of the updip and overlying lower Banquereau Formation shales and siltstones that form very large-scale clinoforms. Polygonal faulting, escarpments and faulted (thins/bumpy) top surfaces indicate downslope movement.

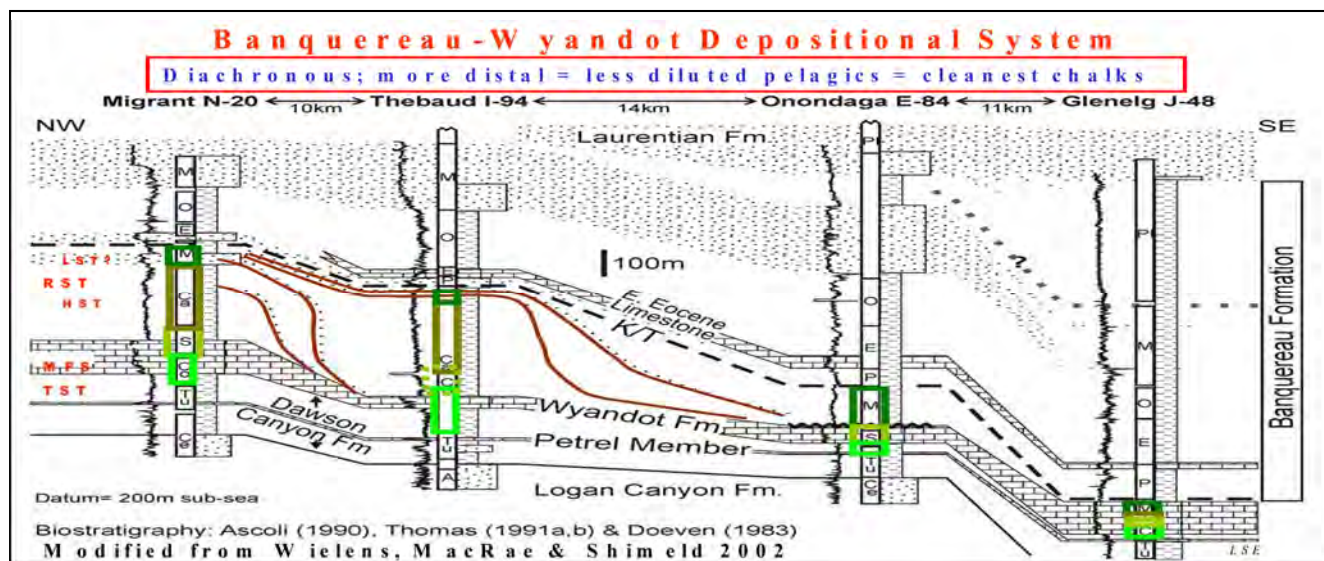


Figure 2. Stratigraphic section showing the diachronous and contemporaneous nature of the upper Wyandot and lower Banquereau formations. Biostratigraphic ages: Pl=Pliocene, Mi=Miocene, O=Oligocene, P=Paleocene, M=Maastrichtian, Ca=Campanian, S=Santonian, Co=Coniacian, Tu=Turonian, Ce=Cenomanian, A=Albian, K/T=approximate Cretaceous/Tertiary boundary. The unconformity identified by Doeven (1983) at Onondaga is indicated with a wavy line. Sequence/Genetic System Tract (ST) terms; TST = transgressive ST, MFS = maximum flooding surface, RST = regressive ST vs HST = highstand systems tract and LST = lowstand systems tract. Gamma ray log for correlation.

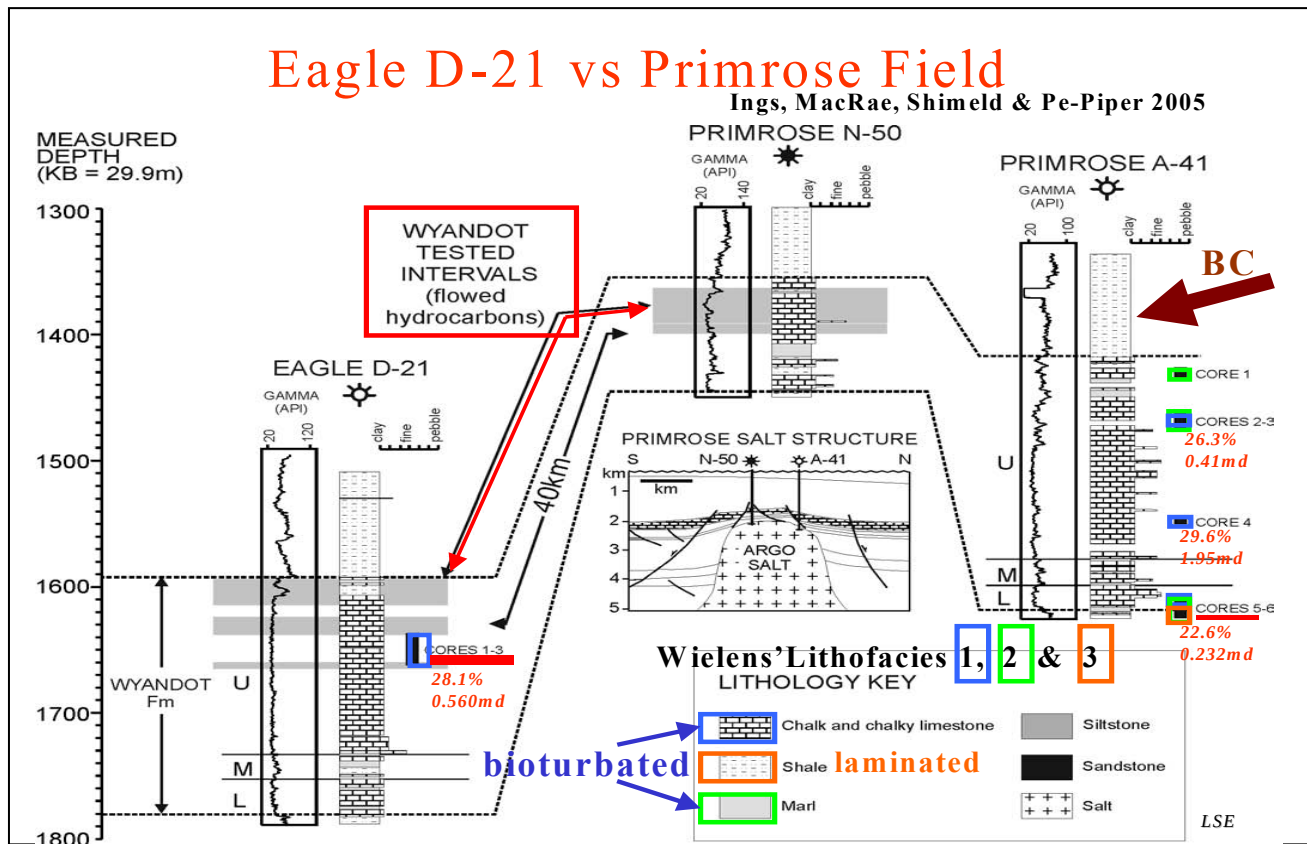


Figure 3. Structural comparison of Eagle D-21 and Primrose Wyandot wells modified after Ings et al. (2005) with addition of Wielens' et al. (2002) generalized Wyandot facies with average porosities-permeabilities for core intervals. Eagle D-21 tested gas up to 1.3MMcfpd, a faulted roll-over anticline and Primrose is gas and oil accumulation on top of a shallow salt dome (shown in CNSOPB salt structure sketch0 but is in a restricted development area (the 'gully').

Closer proximity to Banquereau clinoforms ('BC' arrow) input results in greater gamma/argillaceous character of upper chalk in Primrose compared to the Eagle D-21 and Glenelg J-48 (see Fig. 9); all three distal wells have similar thickness and ages and accumulated over 20 MY from Coniacian to Maastrichtian. The facies (following Wielens et al. 2002) with cores in Eagle D-21 and core 4 of Primrose A-41 a pure Facies 1 with very clean gamma character, compared to Primrose A-41 cores 2-3 and 5-6 which are a mixture with higher clay content. Note the correlation of higher porosity and permeability with the cleanest facies 1 and not depth (although salt dome movement compromises that comparison). 'U', 'M' and 'L' refer to the upper chalk, middle marly and lower chalk subdivisions of MacRae's regional correlations. The argillaceous content of the uppermost Wyandot, can change laterally to shales of the Banquereau Formation up dip as shown in Fig. 9, makes meaningful correlations dependent on seismic data.

Wielens et al.'s (2002) **Wyandot core lithofacies** (used in report):

Lithofacies 1 – white, bioturbated chalk (only facies in Eagle D-21 cores with stylo-laminite subfacies 1A and in Primrose A-41 core 4)

Lithofacies 2 – grey, bioturbated calcareous mudstone (occur in Primrose A-41 cores)

Lithofacies 3 – dark, grey-black laminated mudstone (shale; said to only occur in A-41)



Table 1. Comparison between the studied Wyandot Formation chalk and the North Sea chalk (Ekofisk Field).

PROPERTY	NORTH SEA (GREATER EKOFISK FIELD)	NOVA SCOTIAN SHELF (EAGLE D-21 AND PRIMROSE A-41)
LOCATION	Central North Sea, Norwegian Sector	Nova Scotian Shelf, Canada
GEOLOGIC SETTING	North Sea Central graben, enclosed shelf sea	Sable Subbasin of Scotian Basin, continental shelf
TECTONICS Nature of trap	Reservoirs localized on salt flowage structures (periods of major tectonics and inversion)	Reservoirs localized on top of Argo salt diapir in Primrose and on faulted roll-over anticline in Eagle D-21
RESERVOIR ROCKS Age Stratigraphic Units Lithology Depositional Environment Productive Facies Entrapping Facies (Seal) Diagenesis Pore Types Porosity Permeability Fractures	Paleocene (Danian) and Late Cretaceous (Maastrichtian) Ekofisk (argillaceous much poorer reservoir) and Tor (clean much better) formations Limestone (Chalk) Deep-water-shelf to slope/basin centre, mainly bathyal in an enclosed sea Chalk (overpressured) Paleocene shales (and tight chalk=local ?seals; overpressured, – has arrested compaction diagenesis = high Φ) Compaction (mechanical and chemical), cementation by calcite, clays and silica Interparticle – micro-sized 0-45% (32% average) 0.1-1000 md (1 md average) Abundant in productive interval	Upper Cretaceous (Coniacian-Maastrichtian) Wyandot Formation (Chalk) Distal wells mainly lack argillaceous content Limestone (Chalk) Deep-water – offshore shelf. Deep neritic to upper bathyal on Atlantic continental shelf (distal mixed carb ⁻ -siliciclastic system) Chalk (normal pressured) Cretaceous-Cenozoic Banquereau shales (regionally the condensed distal upper chalk grades up dip into contemporaneous clinoform mudstones of lower Banquereau) Compaction (mechanical and chemical), cementation by calcite and minor clay (unusual stylo-laminites as dispersed thin beds) Interparticle – micro-sized 18.5-35.8 % (averaging 28.1% in D-21 cores) 0.21-1.40 md (averaging 0.56 md in Eagle D-21 cores excluding fractured samples but to 50.6 and avg 1.83 md with fractured) Few in Eagle core, common in Primrose (slickensided)
RESERVOIR DIMENSIONS Depth Thickness Dimensions Production Data	Discovery 1969 9600-10000 ft (2930-3080 m) Several hundred meters of chalk (upper 0-300 m productive) Chalk Group to 2 km thick 8 x 5.5 mi (11 x 8 km) 12071 acres (49 km.sq) 5.4 billion STBO-horizontals & injection up, the ultimate reserves	Drilled 1972 4650-5904 ft (1417-1799 m) in the two studied wells D-21 tested gas at 1.7 MMcfpd over 200 ft (60m) Wyandot Fm to 400m (135 m on average, 200 m in distal wells). Eagle 3 x 5 mi (5 x 8 km) CNSOPB (Primrose off limits) ? Estimated 489 BCF reserves CNSOPB
Some Features in Core		
CHERT NODULES	common	none
FRACTURING	common and effective	rare or of microscopic nature in D-21 core, common in A-41
BIOTURBATION	common; their role is not clear whether they have affected porosity/permeability.	common and positively affected porosity/permeability
COLOR OF THE CHALK	light-gray to medium-tan	different shades of white in Eagle D-21; white to dark brown and green in Primrose A-41 due to glauconite and higher clay content.
CONSTITUENTS	coccolithophores and subordinate planktonic and benthonic foraminifera, fecal pellets, sponge spicules, bryozoans, echinoderms, calcispheres. Clays, pyrite framboids, glauconite, quartz.	coccolithophores and subordinate planktonic and few benthonic foraminifera, bivalve shells, sponge spicules & hexactinellid skeletons, bryozoans, echinoderms, calcispheres. Clays (kaolinite, illite, montmorillonite and rectorite), pyrite and marcasite nodules and framboids, quartz, phosphate fragments (fish teeth/bone), glauconite (in Primrose A-41 only).
DEPOSITIONAL MODE RESEDIMENTATION	Autochthonous and commonly allochthonous resulting in winnowed cleaner better reservoir	Autochthonous only in core. In seismic areas of major mass wasting at top chalk but potential problem of clay mixing
STYLOLITE AND SOLUTION SEAMS	common	solution seams are from microscopic to ~ 6 cm in thickness as dark gray/black laminated thin beds (stylo-laminite).

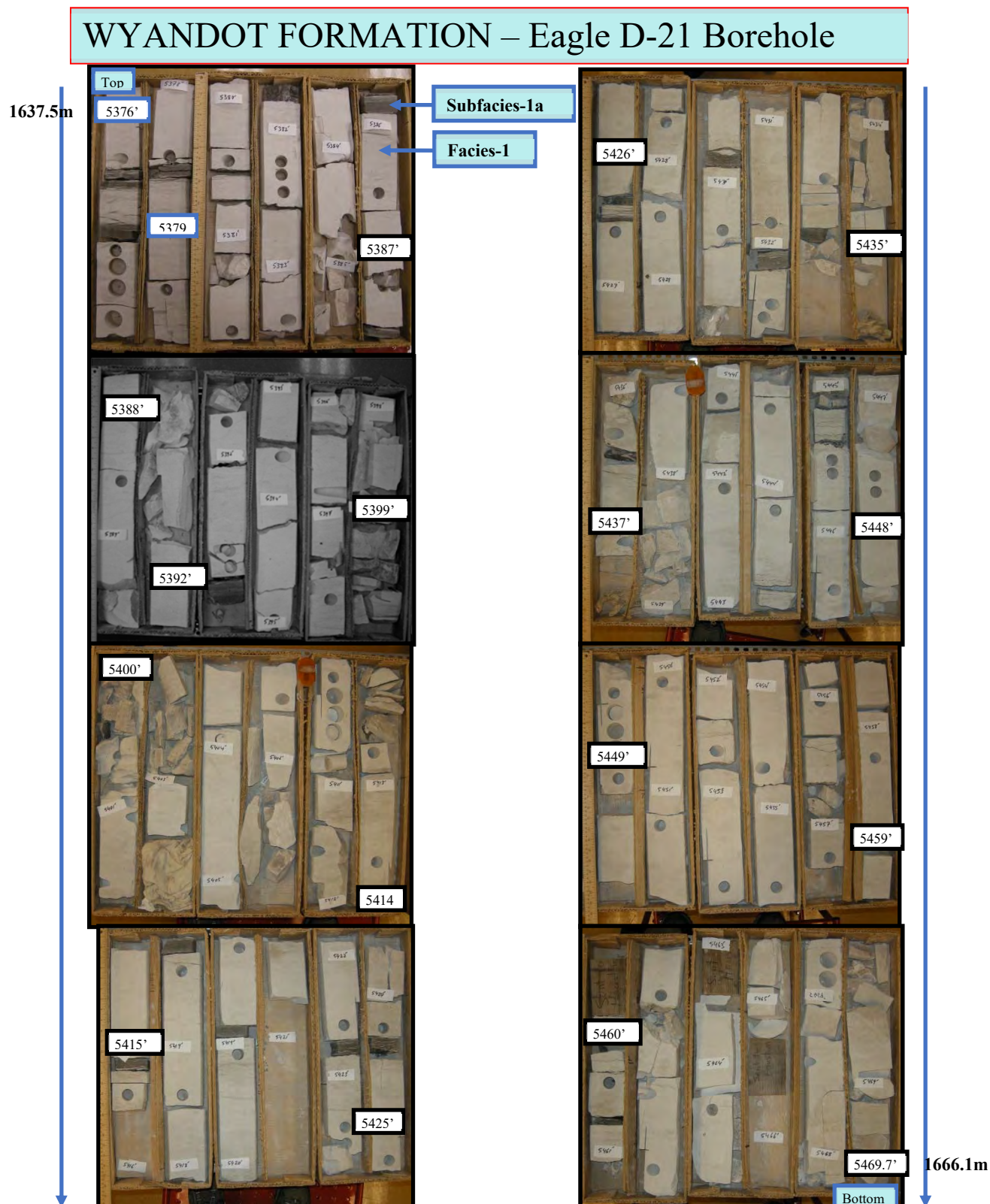


Figure 4. Core images for the EagleD-21 well chalk lithofacies. Comparisons, of white facies (Facies-1= clean bioturbated chalk) and a dark diagenetic subfacies (Subfacies-1a = dark stylolamine from pressure dissolution). Depth mainly in feet (') as drilled and in core boxes except top and base in metres too. **Core width ~ 10-12 cm**



Figure 5. Eagle D-21 schematic core diagram from 5376 feet (1638.6 m) to 5471 feet (1667.6 m). Modified from Ings et al. (2005) showing their and this reports sampling sites. Note that some of the parameters such as gamma ray are highly exaggerated scales. Stylo-laminite thin beds (Facies 1A) are interpreted to lower porosity in the closely adjacent clean white chalk (Facies 1) giving an inverse increase of porosity with depth locally as opposed to the usual decrease with burial regionally and globally for chalk.

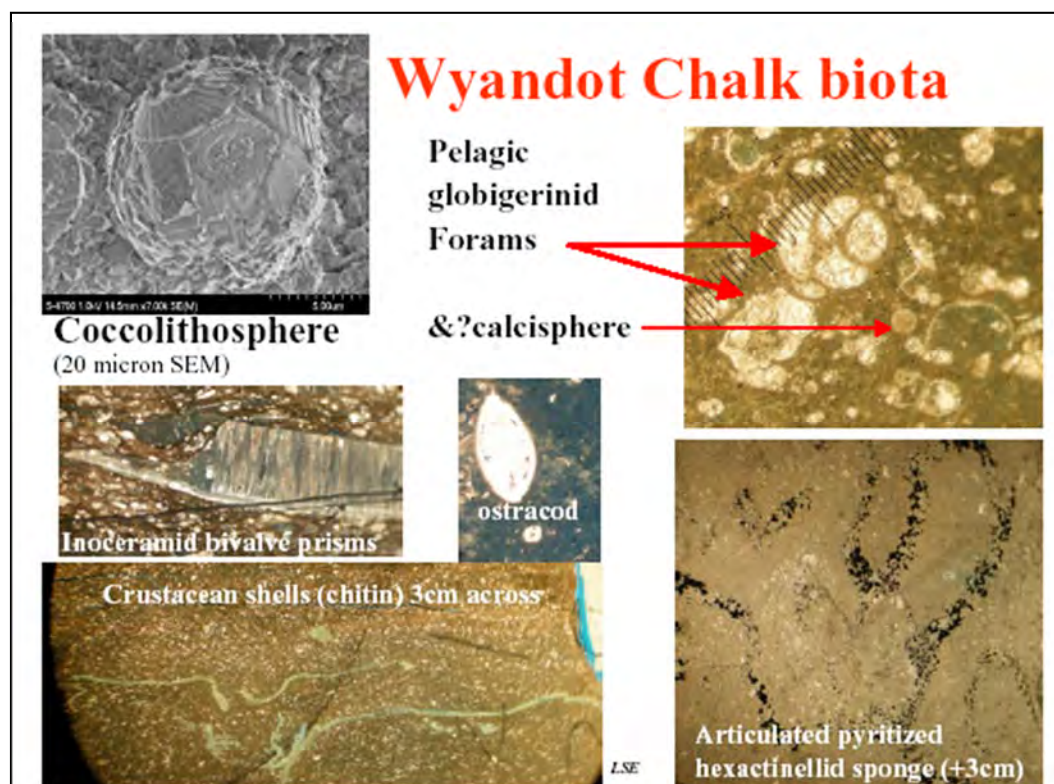
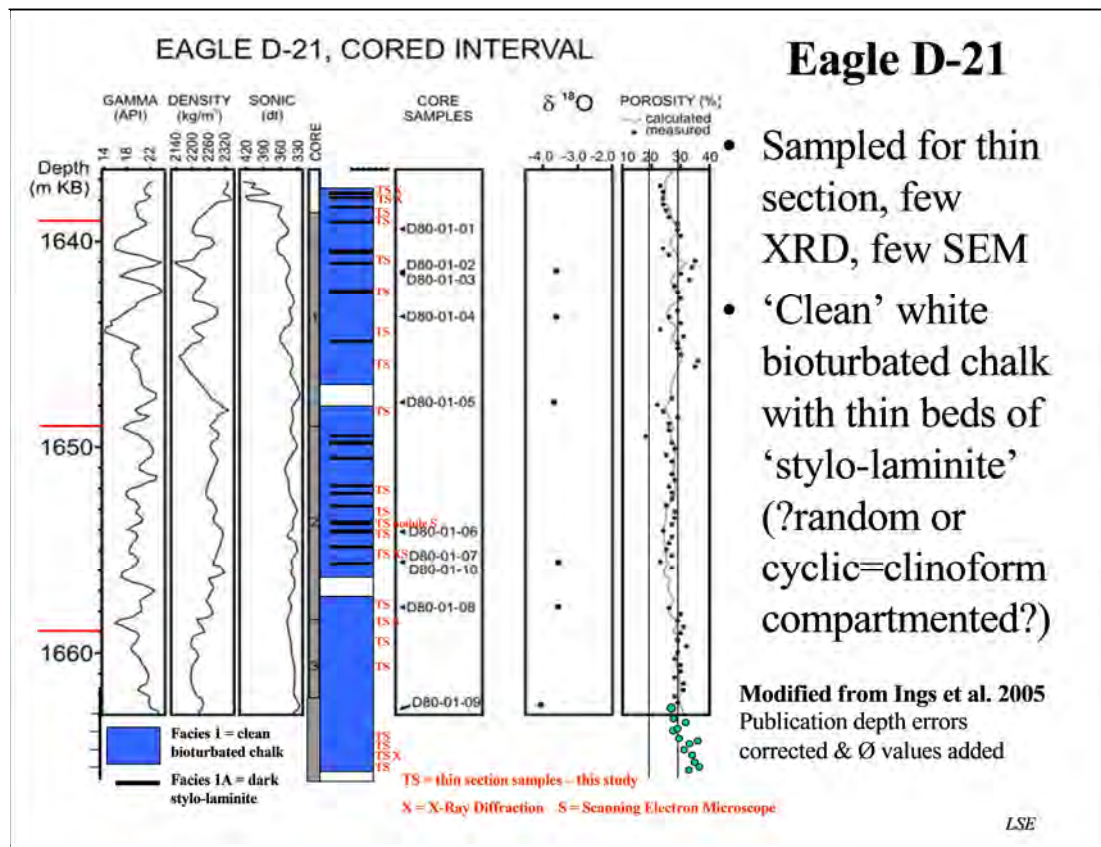
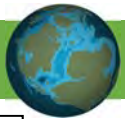


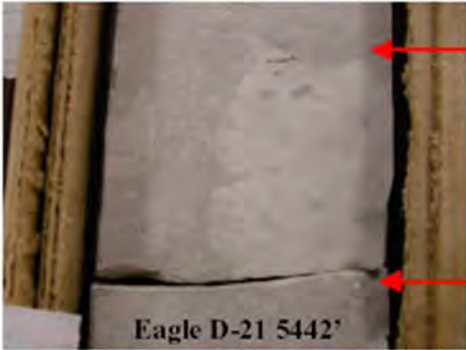
Figure 6. Wyandot chalk is dominantly pelagic nannofossils with accessory microfossils mainly forams and rare macrofossils once able to live in carbonate ooze or swim over it.



Wyandot Chalk Biota & ?Firmground



Eagle D-21 5430'



Eagle D-21 5442'

- **Inoceramid shell bed** = largest fossil in chalk that likely "floated" on top of ooze filter-feeding pelagic 'rain'
- **?Firmground** = only occurrence in Eagle core and equivocal. Lack of hard substrate fossils like bryozoa, crinoids, corals is another indicator of lack of hardgrounds. Therefore likely little early seafloor cementation

LSE

Figure 7. Inoceramid clams were the largest benthic organism and rarely occur as thin shell beds but mostly as remnant shell-wall prisms. Only evidence of seafloor cementation was a single dubious firmground between the two occurrences of small whole skeleton hexactinellid sponges

Wyandot Chalk Ichnofauna

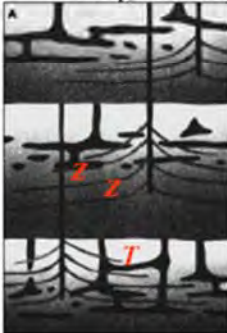
- Highly burrowed oxic setting with *Zoophycos*, *Thalassinoides* & small *Chondrites* (latter often mining larger burrows; associated with dysoxia sometimes)
- Tiering can pipe sediments down connecting different porosity-permeabilities – *Thalassinoides* often seems 'cleaner' vs small *Chondrites* is finer with less forams and often pyritic & dark ?organic infills



Thalassinoides

Zoophycos

LSE



A



B

Burrow-enhanced permeabilities in unconstrained textural heterogeneities - Pemberton & Gingras 2005

Figure 8. The main evidence of slow sedimentation in oxic bottom waters, and plentiful organisms is the complete de-stratification of the sediment. Some burrows seem to now be more porous than adjacent sediment. Such reservoir enhancement has been documented for carbonates but not chalks as yet (Gingras and Pemberton 2005).

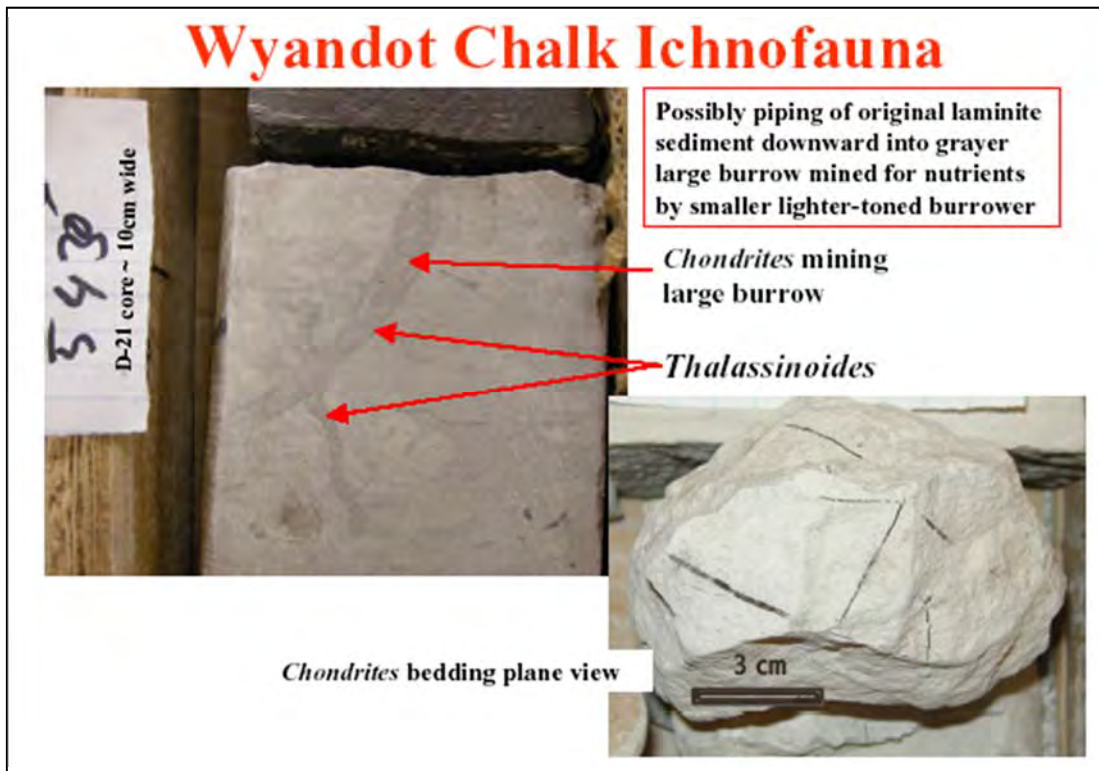


Figure 9. Burrows can give sedimentological insight to depositional settings but also to the possible nature of original sediment now diagenetically-removed.

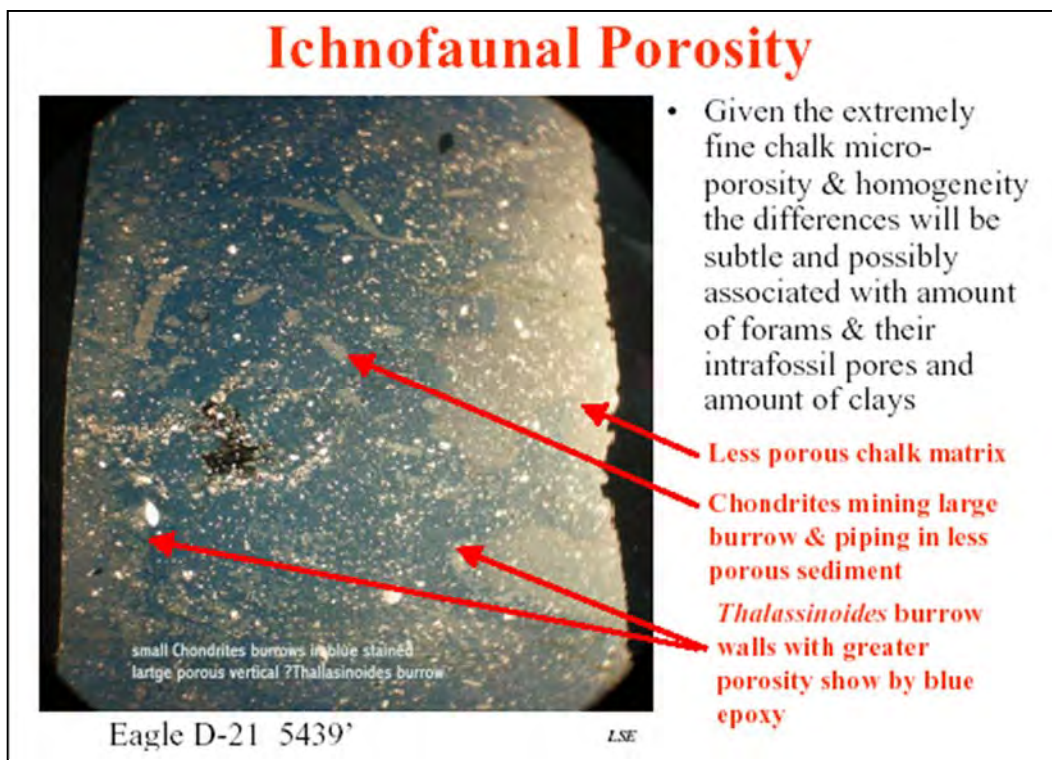


Figure 10. Interpreted ichnological enhancement of porosity. Compare this microphotograph with the macrophoto in Fig.9 for an analogue at different scales.



Stratigraphy and sedimentology of the Lower Missisauga and Mic Mac Formations in the Migrant rollover structure, Sable Subbasin, offshore Nova Scotia.

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Abstract

The deltaic reservoirs of the Lower Cretaceous Missisauga and Upper Jurassic Mic Mac formations are a highly prospective interval for hydrocarbon exploration in the Sable Subbasin with many gas and condensate discoveries and some production. Targeted by the Migrant N-20 well, the Migrant structure is a four-way dip closure formed on the hanging wall of listric growth fault. This part of the subbasin has an active petroleum system and abundance of reservoirs. Yet, the sands in this structure are almost entirely wet.

Preliminary petrophysical analysis of the gamma ray log shows an anomalous bottom sand interval at the base of a fining upward sequence in the lower section of the N-20 well. This log signature agrees with the idea of an initial pulse in deltaic sedimentation followed by a slowly transgressing sequence. Although the absence of cores from the Migrant Structure makes it almost impossible to directly analyze this anomalous unit. Instead, we must correlate the unit to nearby cored wells to visualize the facies change.

Considering the fault sealing mechanism in the genetically related downdip Thebaud structure (a possible analogue to Migrant), we elected to use full diameter cores from the Thebaud I-93 well, which captures aspects of the transition between the reservoir (sandy) and non-reservoir (shaley) units and their associated sedimentary features. In this presentation, we describe the facies change in the Thebaud I-93 top core (3065.68-3081.27mRT) and analyze the change in grainsize and sedimentary features as well as the associated sandstone composition for comparison to Migrant.

Introduction

The deltaic reservoirs of the Lower Cretaceous Missisauga and Upper Jurassic Mic Mac formations are a highly prospective interval for hydrocarbon exploration in the Sable Subbasin with many gas and condensate discoveries and production. The reservoir quality of each formation offers insights to changes in their observed paleoenvironments at the time of their deposition.

Targeted by the Migrant N-20 well (**Figure 1**), the Migrant structure is a four-way dip closure that formed on the hanging wall of a listric growth fault. This part of the subbasin has an active petroleum system and abundance of reservoirs. Yet, the sands in this structure are almost entirely wet

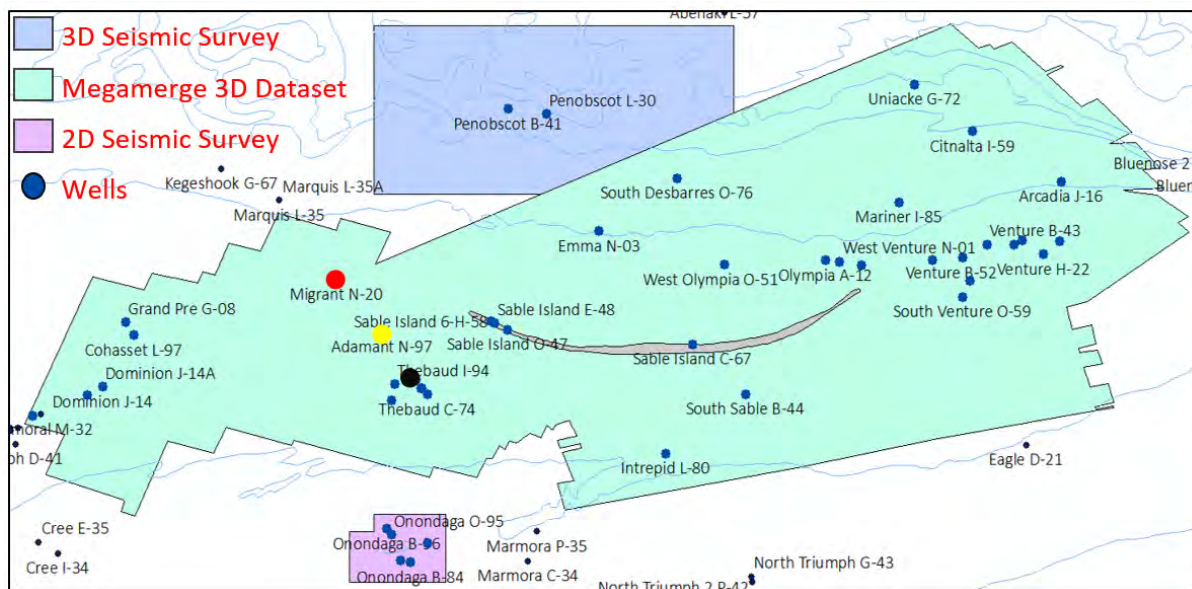


Figure 1. Map showing the location of key wells for this study. The Migrant N-20 well is defined by the red dot but has no core information available for this study. The Adamant N-97 well, 6.5 km southeast, is indicated in yellow and has only side wall cores. The Thebaud I-93 well, 6.5 km south of n-97, has a number of full diameter and side wall cores and is represented by the black dot.

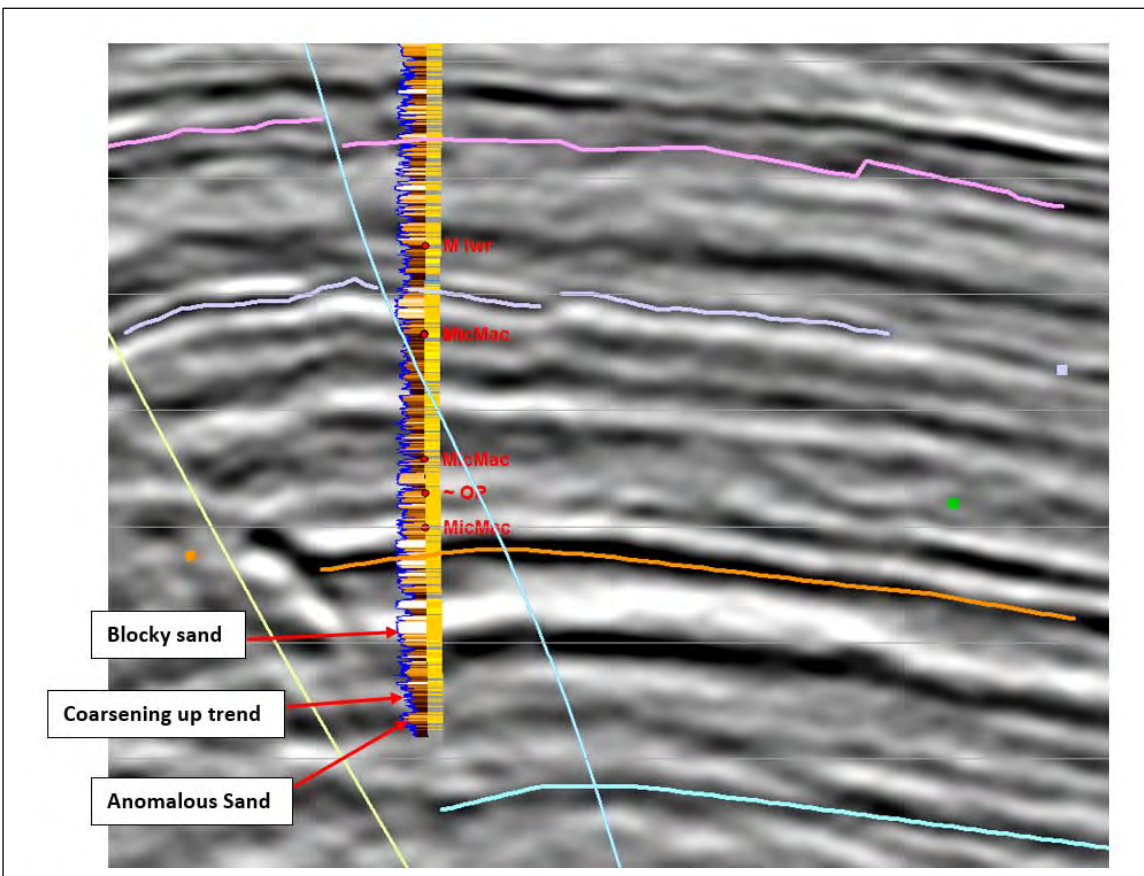


Figure 2. A NW-SE oriented seismic section showing the location of the Migrant N-20 well from this study with key interpretations and annotations. No conventional cores were recovered from this well.



An anomalous sand reservoir at the base of a fining upward sequence in the lower sections of the N-20 well (**Figure 2**) typifies a pulse of deltaic sedimentation comprising a high net-to-gross sequence followed by a slowly transgressing sequence. However, though cuttings samples and well curves are available, the absence of conventional and sidewall core data from the well makes it difficult to determine its reservoir characteristics and depositional environment, and directly integrate with the seismic dataset. The use of conventional and side wall cores from nearby wells Adamant N-97 (6.5 km southeast) and Thebaud I-93 (13 km south-southeast) was thus required to assist in describing the Migrant N-20's interpreted Mic Mac Formation reservoir sandstone.

Stratigraphy

After development of full marine conditions in the Sable Subbasin in the Mid Jurassic, the area saw the establishment of a combined siliciclastic deltaic and carbonate succession. The Sable Delta prograded into the basin from the northeast, with the Abenaki Formation (Bajocian to Tithonian) carbonate platform present to the northwest following the basin's faulted hingeline margin. The shallow marine Mic Mac Formation (Callovian to Tithonian) corresponds to a mixed carbonate – clastic system comprising sandstone and limestone top sets, sandstone to shale forests, and shale to sandstone bottom sets deposited in the Mid to Late Jurassic (Wade & Maclean 1990). The Early Cretaceous Missisauga Formation (Tithonian to Barremian) overlies the Mic Mac and is comprised predominantly of thick fluvio-deltaic sandstones that represents the majority of the hydrocarbon-bearing reservoirs on the Scotian Margin (CNSOPB 2009). It is a high net-to-gross succession that shows no obvious transitional contact with the underlying Mic Mac Formation in the Sable Subbasin (Wade & Maclean 1990).

Study Results

For this study, we integrated wireline data and stratigraphic core descriptions with modern geochemical techniques to analyze the reservoir facies and their associated environments of deposition in full diameter cores for the Thebaud I-93 well. These data and interpretations were compared these with existing data from the coreless Migrant N-20 well. Stratigraphically, the I-93 core is most related to the non-overpressure interval in the Migrant structure 13 km to the northwest that contains the anomalous reservoir. A predominance of deltaic sands, with thin shales identified from wireline logs and bioturbated interbedded sands, shales and silts characterizes the top core of the Thebaud I-93 well representing the Missisauga Formation (**Figure 4**).

Generally, fault sealing is most effective at the top of the Missisauga Formation below the ~200 m thick Albian Naskapi Member shale interval (Logan Canyon Formation; Albian to Cenomanian) and in the deeper Jurassic sections. Although thick shale intervals exist within the Missisauga Formation, a thick shale interval present in the middle of the formation (Thebaud Shale) constitutes the key control on hydrocarbon trapping in the Thebaud gas field and is the capping seal for the over-pressured interval below it. By mapping/correlating the top of overpressure in the Adamant and Migrant structures, we see how it changes stratigraphically (climbing higher to the northwest towards Migrant) and at the faults. In some wells around the study area, the top of overpressure matches with the Thebaud Shale. However, in other places, it appears to climb stratigraphy.

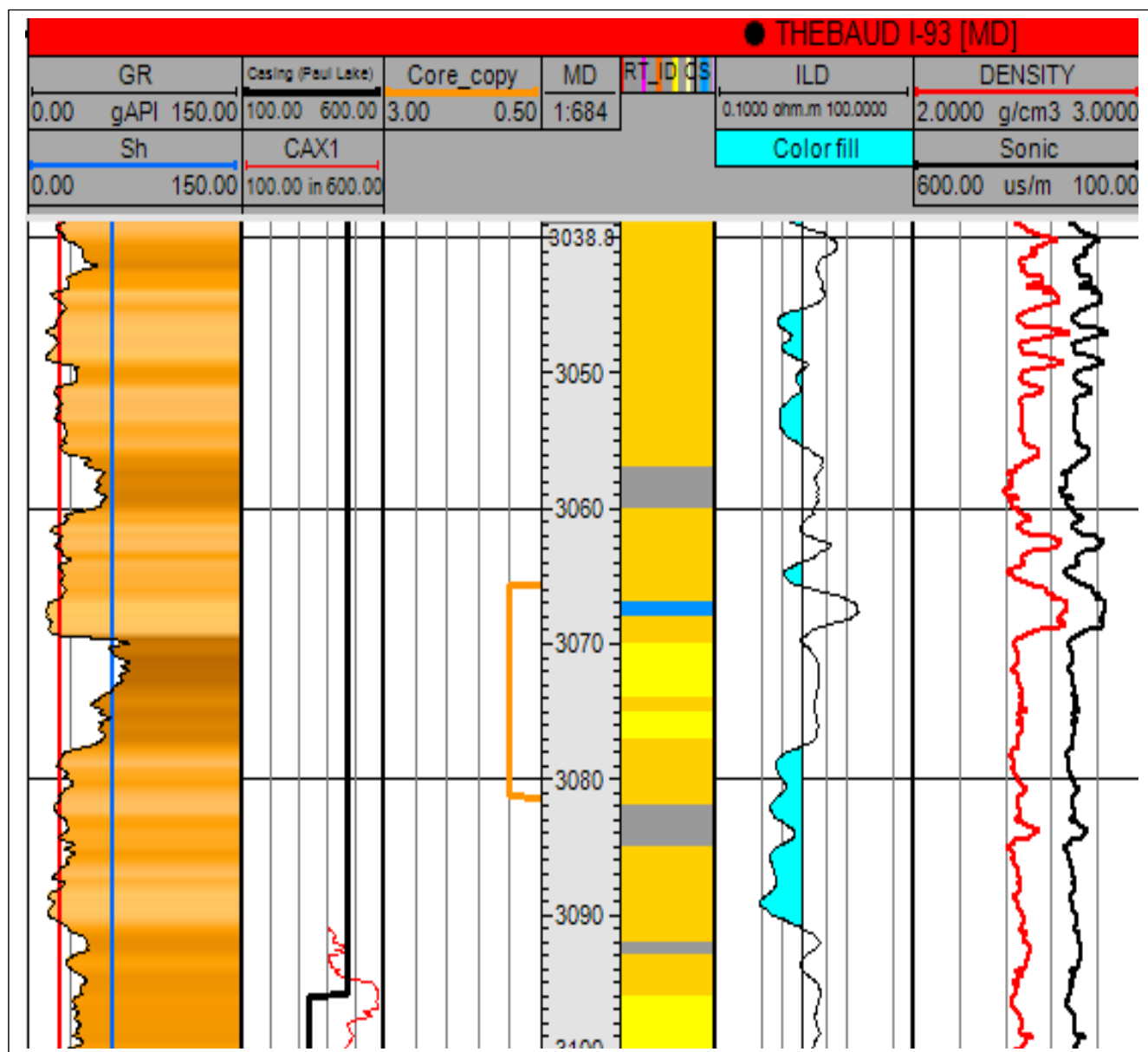


Figure 3. A log composite of the Thebaud I-93 well showing the gamma ray track on the far left providing lithological characteristics. The orange bar shows the interval of core coverage (Core No. 1; 3065.68-3081.27m MDRT). The curves in the right show the density and sonic logs placed in the same track and the resistivity log in the track to the left with aqua shading highlighting where resistivity values are under 2 ohms. The change in resistivity from a couple of ohms to 10 - 20 ohms in a porous zone is a possible indication of a gas leg.



Figure 4: Photo compilation of slabbed core from the Thebaud I-93 well's core No. 1 (3065.68-3081.27 m MDRT). The small white squares with black markings indicates the point where X-ray fluorescence XRF measurements were collected for rock classifications according to Herron (1988). Though comprising only a short interval with minimal recognizable change in depositional environments, analyzing the physical rock characteristics and grain size distribution provided further information with regards to the energy level at different depths and how this transitioned upwards through time. Scale bar is 15 cm / 6 inches long.



Conclusions

The absence of conventional cores from the Migrant N-20 well required the use side wall cores from Adamant N-97, and full diameter cores from the Thebaud I-93 and other wells at the Thebaud field (**Figure 1**). Although sidewall cores do not adequately capture stratigraphic transitions, we focused on selecting cores that illustrated the transition from reservoir to non-reservoir with their associated sedimentary features.

Understanding the sediment thickness relationship between older and younger stratigraphic successions provides information of the timing of fault movement. As a result, sediment deposition with no equivalent on the landward (footwall) side of the major bounding fault at Migrant ceased at the time of deposition of younger sediments that have equivalents on the both sides of the fault. Thus, mapping the anomalous sand will reveal if it is continuous or pinches out.

Acknowledgements

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Varied Carbonate Facies from the Jurassic-Cretaceous Gigaplatform Margin of the Baltimore Canyon Trough offshore Delaware, USA

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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:

1. Oxfordian-Kimmeridgian prograded margin (R1+2) and slope (C3).
2. Late Kimmeridgian-Berriasian aggraded margin capped by pinnacle reefs (C2, H3+4) followed by an extensive deeper-water mounded sponge-rich interval of Berriasian and Valanginian age (R2, C1, H2).
3. 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.

NOTE: This presentation is a slightly modified and reformatted version of the original first presented (and published in a CD volume) at the CSPG 2005 Core Conference, and is presented here with permissions from the Canadian Society of Petroleum Geologists and Royal Dutch-Shell.

Introduction

The carbonate cores on display result from deep-water drilling by Shell Offshore Incorporated (SOI) and partners in the mid 1980’s of three 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. Encana's (PanCanadian) 1999 discovery of the Deep Panuke gas field in the Jurassic carbonate offshore Nova Scotia (Weissenberger et al. 2000) 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 three play types (their informal operational names are the basis of core letter abbreviations of the abstract).

- SOI et al. OCS-A 0317 in the Wilmington Canyon Block 372 ('Hyena' = H1-4 cores) tested a platform Jurassic-Cretaceous margin "pinnacle play".
- SOI et al. OCS-A 0337 in the Wilmington Canyon Block 587 ('Civet' = C1-3 cores) tested a Jurassic-Cretaceous near-margin "mesa or mound play".
- SOI et al. OCS-A 0336 in the Wilmington Canyon Block 586 ('Rhino' = R1-4 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). In particular were the litho-depofacies studies in an unpublished 1985 report by Leslie Eliuk and 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. Meyer (1989) published some aspects of this information 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 (Figure 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; Figure 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 (Figure 11A 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 those of Ringer and Patten (compare **Figure 9** with Erlich et al.'s 1990 Figure 4). 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.

The Baltimore Canyon cores were first shown publicly in 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. Recently Eliuk has reinitiated study of these cores explaining why USA cores are in Calgary (2005) and Halifax (2007-2018) and this ongoing newer work will 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). This presentation mainly reflects the work of two or three decades ago. However, it was appropriate for the 2005 AAPG conference in Calgary and likewise here where it may give insights for revived Nova Scotia and United States Atlantic offshore carbonate margin exploration.



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). Three major mid-Mesozoic reef-reef mound types were known from the mid-late 1970's offshore Nova Scotia: coral, siliceous sponge and mud (microbial) mound (Eliuk 1978, Eliuk 1981). The past decades has 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).

Baltimore Canyon Carbonate Lithologies and Depositional Interpretations

The three wells in this region were drilled in over 1.5 km (5000 feet) of water testing different prospects and play types always in closure as defined by seismic (**Figures 2 a & b** and **Figure 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 (**Figures 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 (**Figure 5**). Thus, the shelf interior, prograding and aggrading margins and slope seismic geometries can be linked to lithologic control. 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 **Figure 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 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 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 (**Figure 5**). The cores allow a 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 (**Figures 10, 12, 14, 16 and 17**).

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 the 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 (**Figure 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 wells 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 lithologically. 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 well 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 the 0336 and 0337 wells 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 well 0317 may be as young as deep-water carbonates behind the shelf-edge in well 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, 12, 14 and 16** and as photographs of representative lithologies on **Figures 11, 13, 15 and 17**. Limestone classification is based on Embry and Klovan (1971). A summary diagram (**Figure 4**), showing schematic well lithologs, which were also used on the seismic section through these wells (**Figure 3**), groups the cores into similar depositional facies. Excluding the Aptian shelf margin oolitic Core #1 (R1) in well 0336 and the Albian slope shale Core #1 (H1) in well 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-intra Valanginian 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).



Well 0317 ("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 (Flügel and Steiger, 1981). In a similar manner, they consist of burrowed, tuberculitic (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 - not shown) - 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. 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.

Discussion and Conclusions

At present, the Baltimore Canyon Trough and Scotian 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. However, 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 display by Wierzbicki et al. (2005; CSPG core conference) 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 ramp (Eliuk 1978, Wierzbicki et al 2005). When the upper flexure more proximal portion of the ramp margin is sampled in Nova Scotia as in Panuke F-09 there is very little reefal beds and a lot of oolitic grainstone even though the well is less than 2 km from the edge. Note the Abenaki “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 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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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 the CSPG CD).

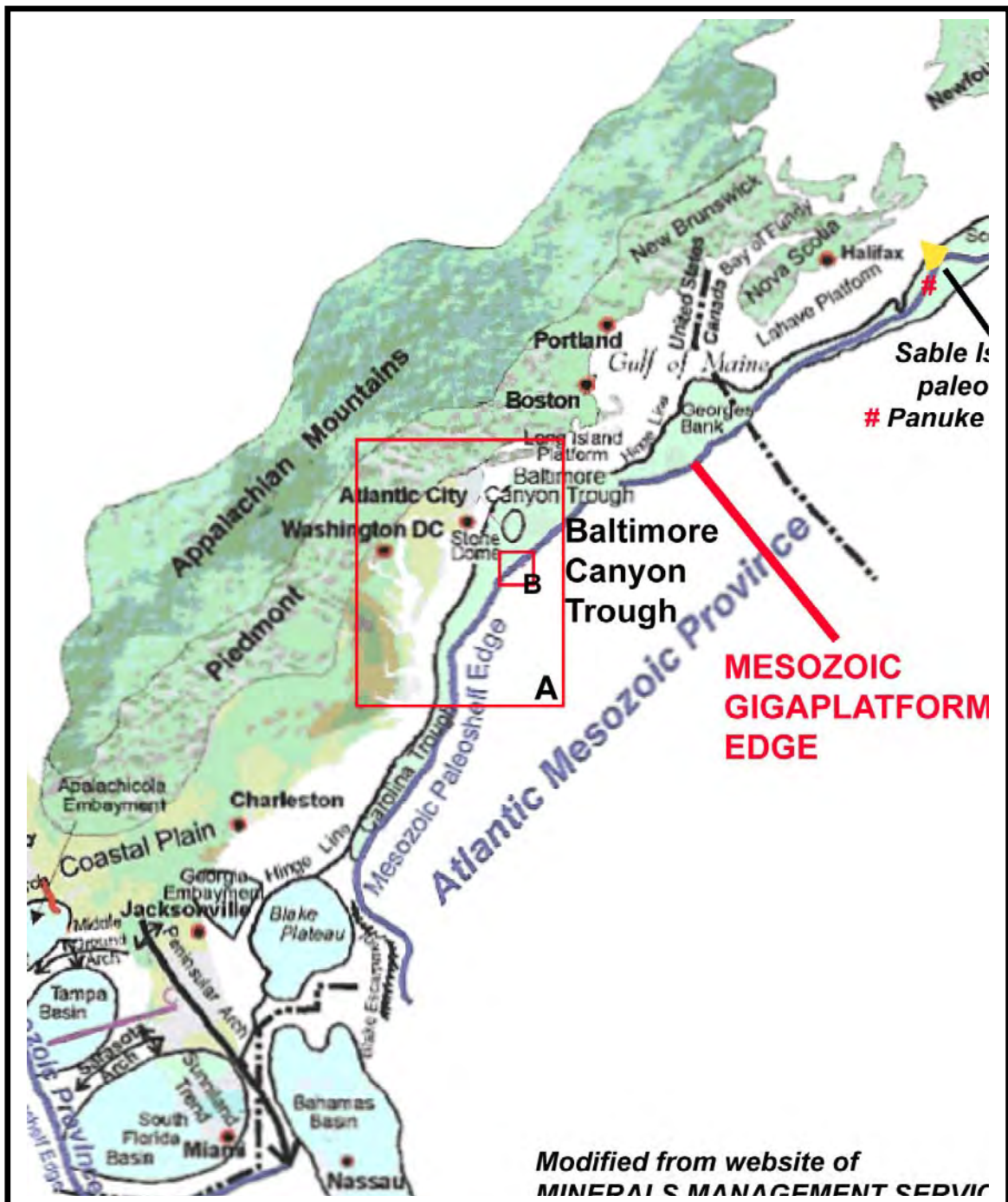


Figure 1. Atlantic margin regional physiographic-basin map showing the location of the Baltimore Canyon Trough and **Figure 2a** and **Figure 2b** map outlines. The edge of mid-Mesozoic gigaplatfrom (Poag 1991) is shown from the southwest Grand Banks to the Bahamas. Deep Panuke gas accumulation just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

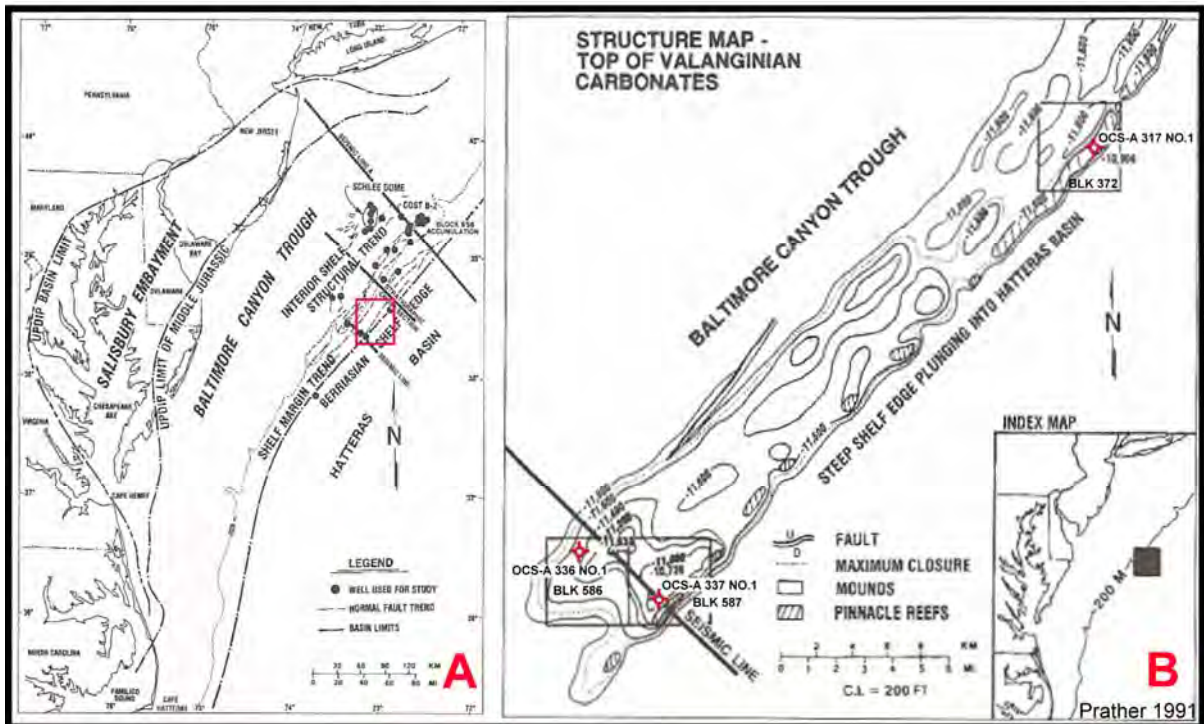


Figure 2. Baltimore Canyon Trough maps from Prather (1991): **A**) outline of basinal Trough showing the Late Jurassic-Berriasian shelf margin trend in deep water beyond the present-day shelf edge, **B**) top drowned Berriasian carbonate shelf margin structure map showing the high relief pinnacles-raised 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)

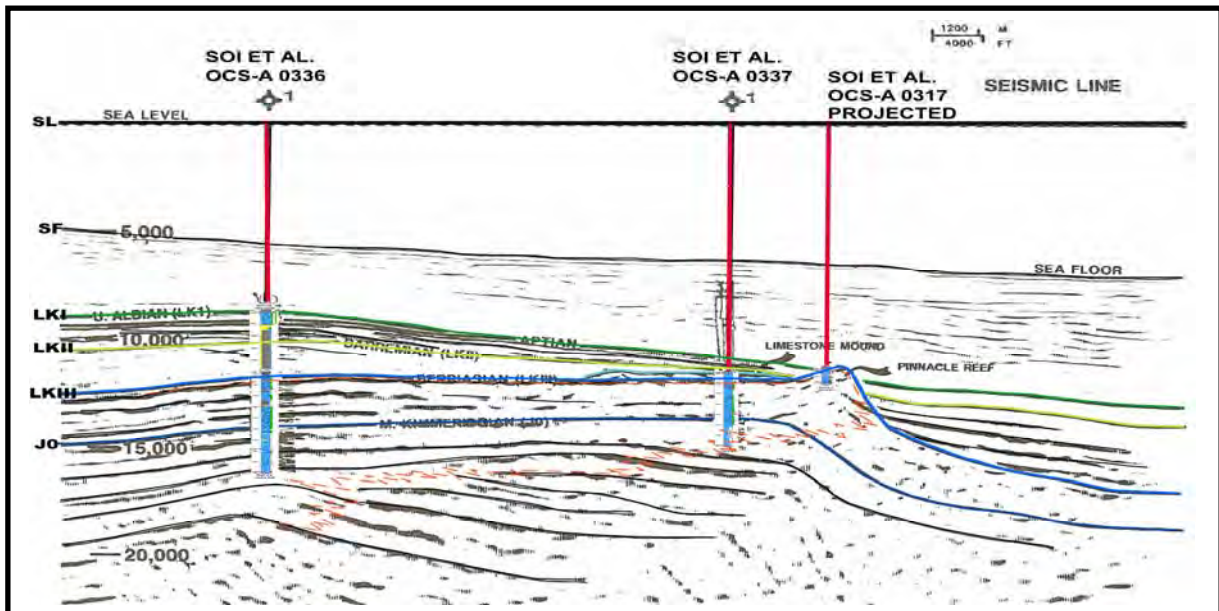


Figure 3. Dip seismic line through OCS-A 0336 and OCS-A 0337 with OCS-A 0317 projected from northeast (see Fig 2b for location of line and wells; modified from Prather 1991). Note the raised rim or pinnacle reef right at the margin edge tested by OCS-A 0317 on the landward flank down from the crest and 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 with slope facies below and eastward.


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

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	(A)	15690' (basal 310')	not penetrated	
(near-Oxfordian?)				

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)

LK1 - about level of mid Albian lacuna (Aptian carbonate margin with OCS-A 0336 core #1 between LK1 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)

Facies/Lithology	number of beds	CNL/FDC porosity			Permeability (based on perm plug measurements*)		
		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	Permeability
					Average (Range)	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

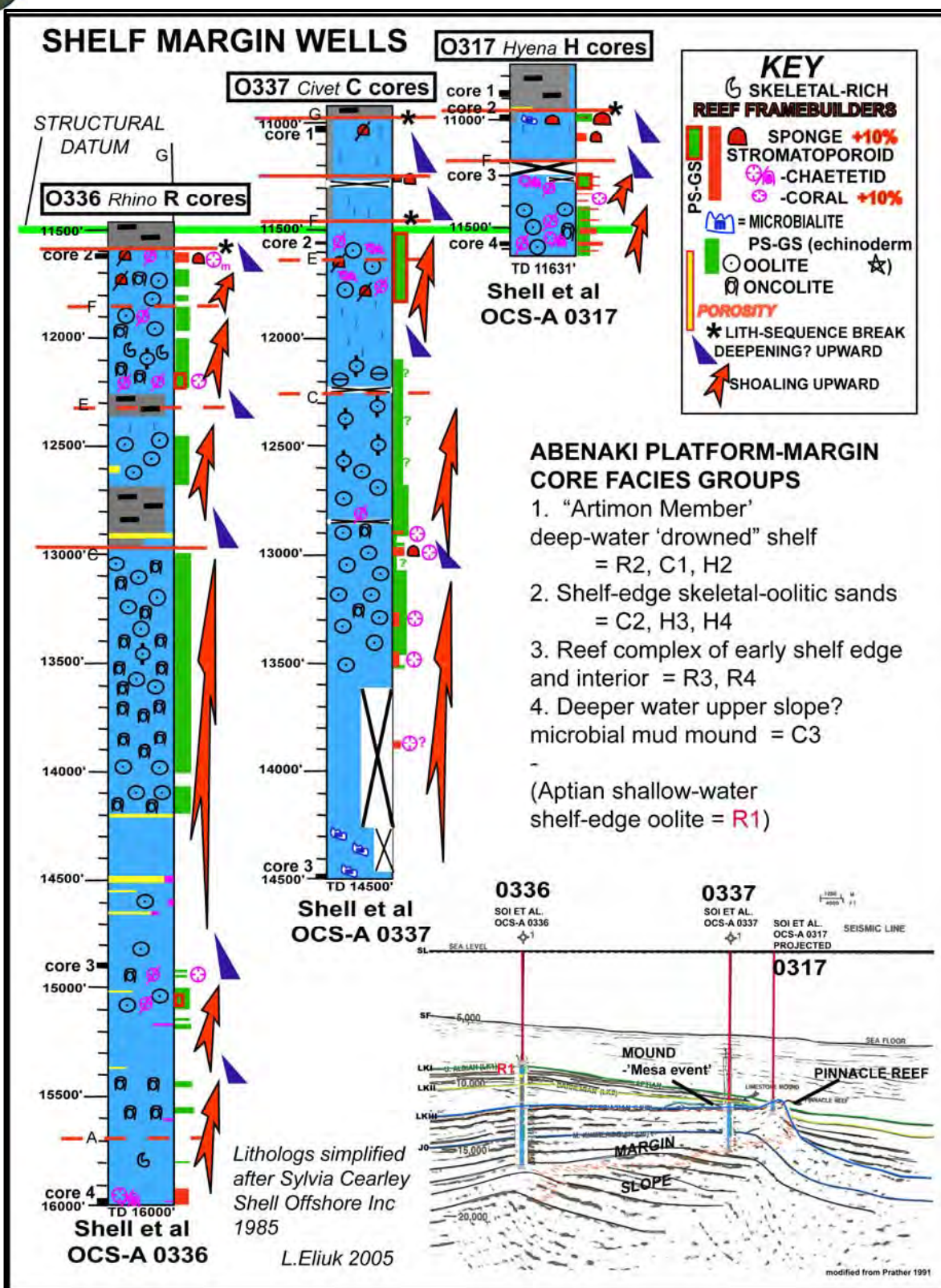
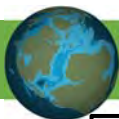


Figure 4. Shelf margin wells schematic lithologs of Shell OCS-A 0336, 0337 and 0317 based on cuttings and core logging. See Table 1 for approximate ages of biostratigraphic markers (letters on left). The cores have been grouped by major depositional facies and their position is shown on the logs. See 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).

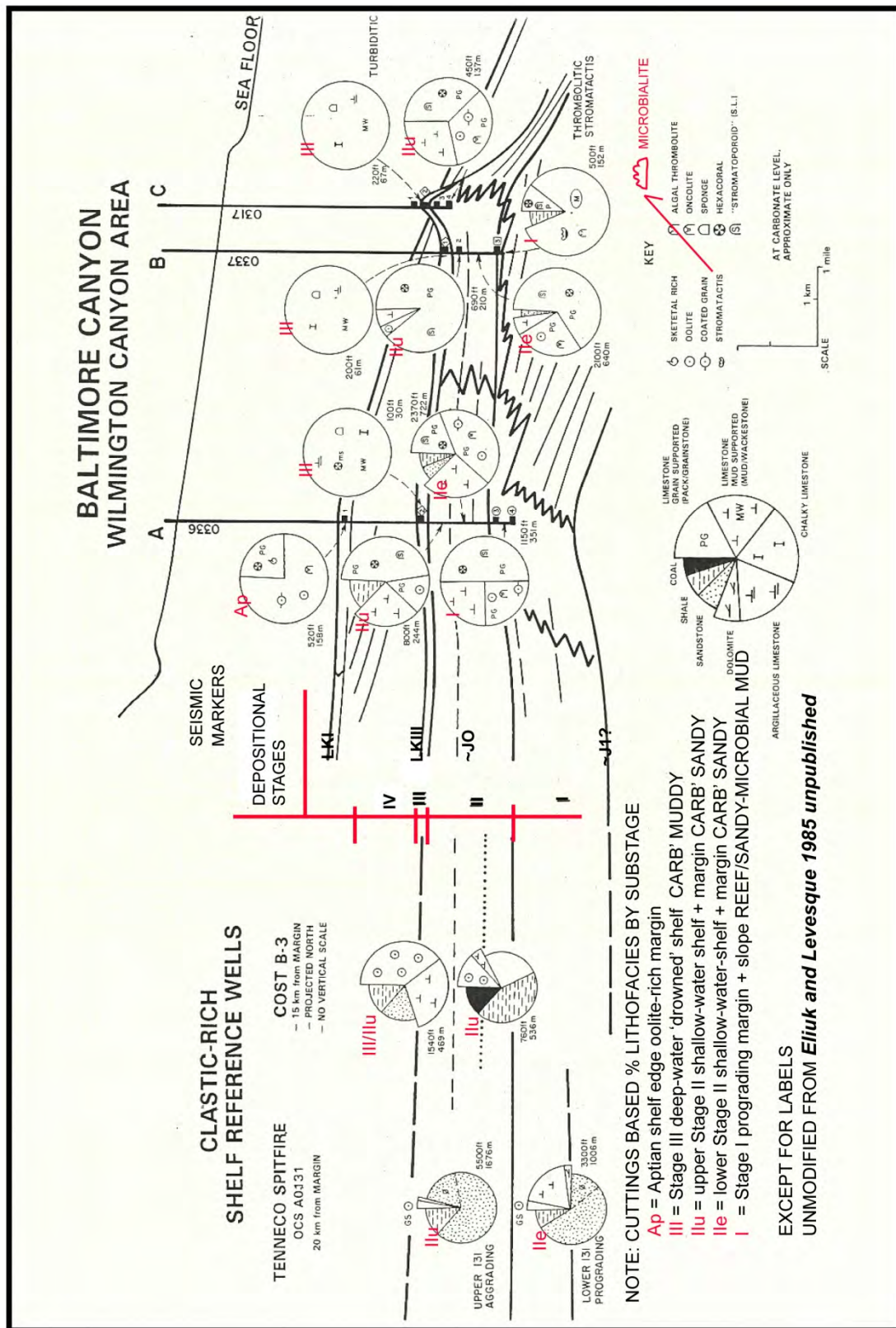
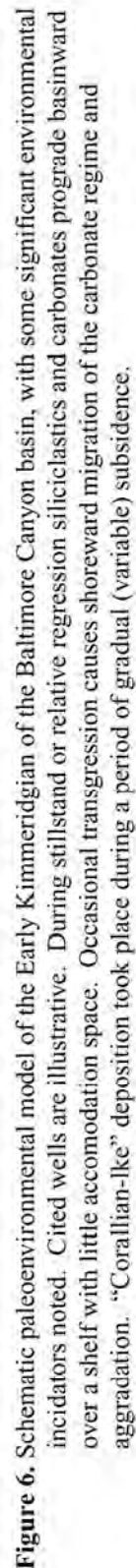


Figure 5. Percentage lithofacies from well cuttings by depositional growth stages (see Meyer 1989 for moreinterpretation and a complementary block depositional model). Note the large amount of skeletal/framebuilder and oolitic/oncolitic grainstones-packstones indicating relatively open high-energy shelf 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’



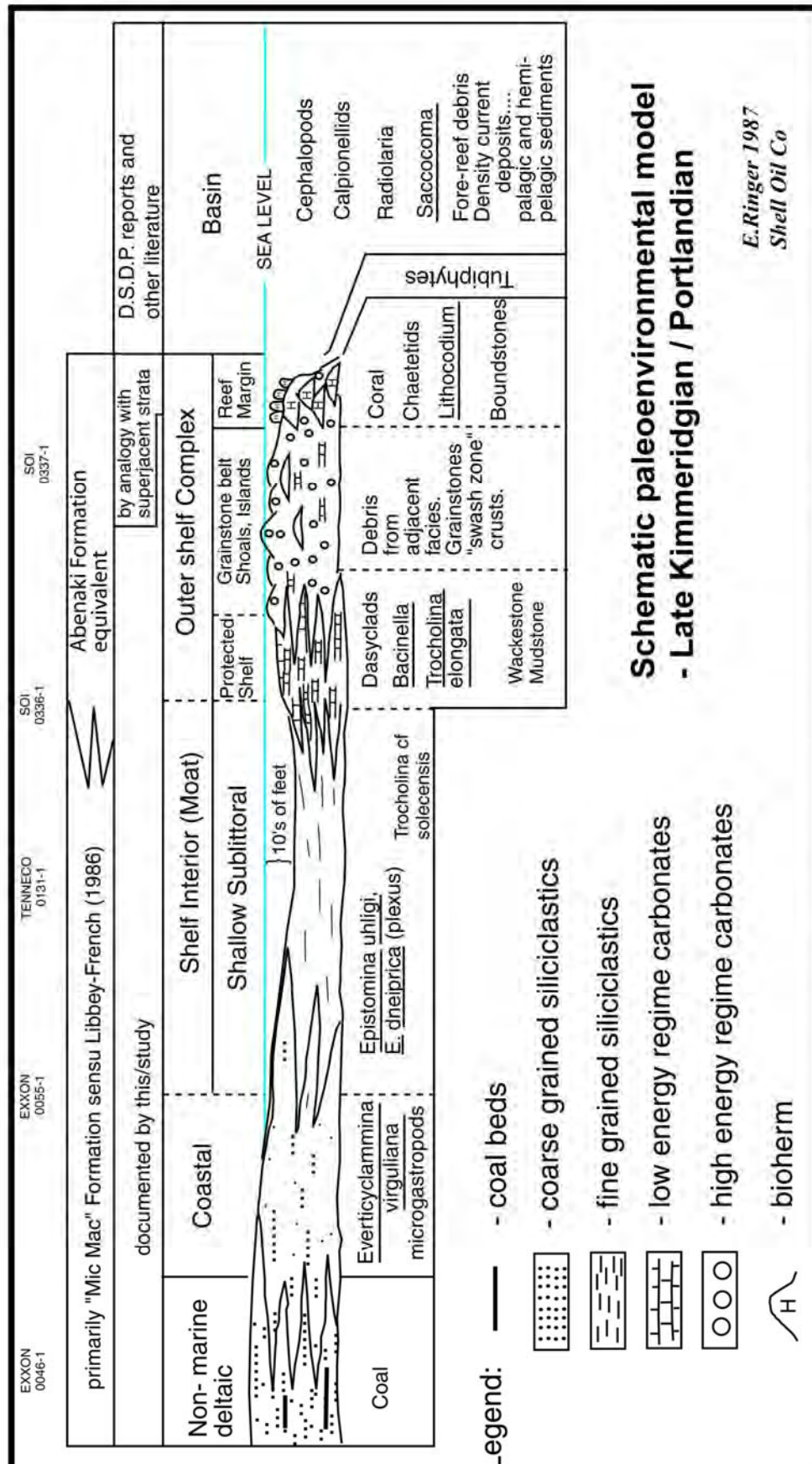


Figure 7. Schematic paleoenvironmental model for the Late Kimmeridgian/Portlandian found in the Baltimore Canyon Basin, with some significant environmental indicators noted. Cited wells are illustrative. Shelf is subdivided into coastal, paralic, shelf interior, intra-shelf basin ('moat' facies of Eliuk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

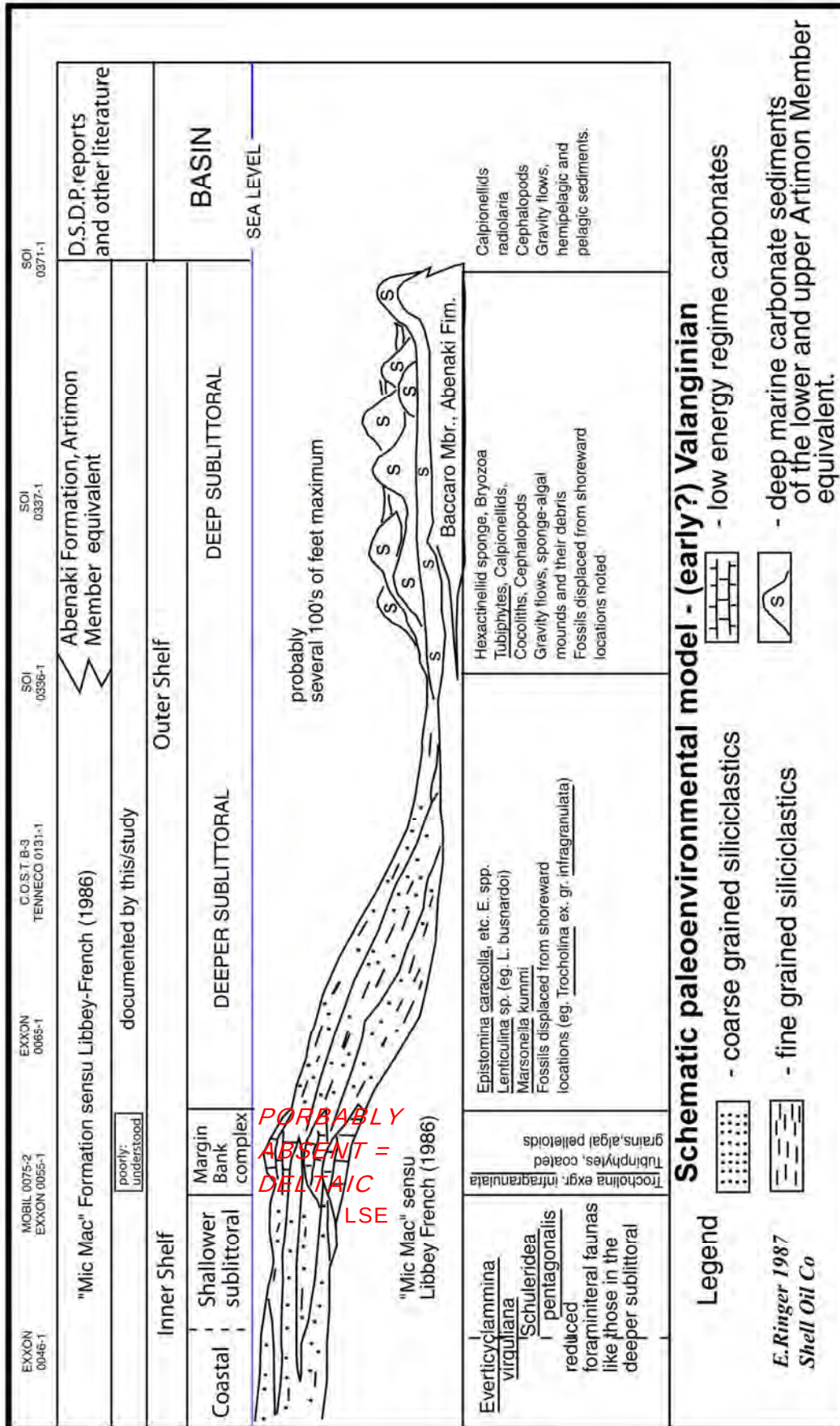


Figure 8. Schematic paleoenvironmental model for the (early?) Valanginian of the Baltimore Canyon Basin, with some significant environmental indicators noted. Cited wells are illustrative. Note the shoreward displacement of margin bank (possible Knowles equivalent) due to eustatic rise in sea level during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

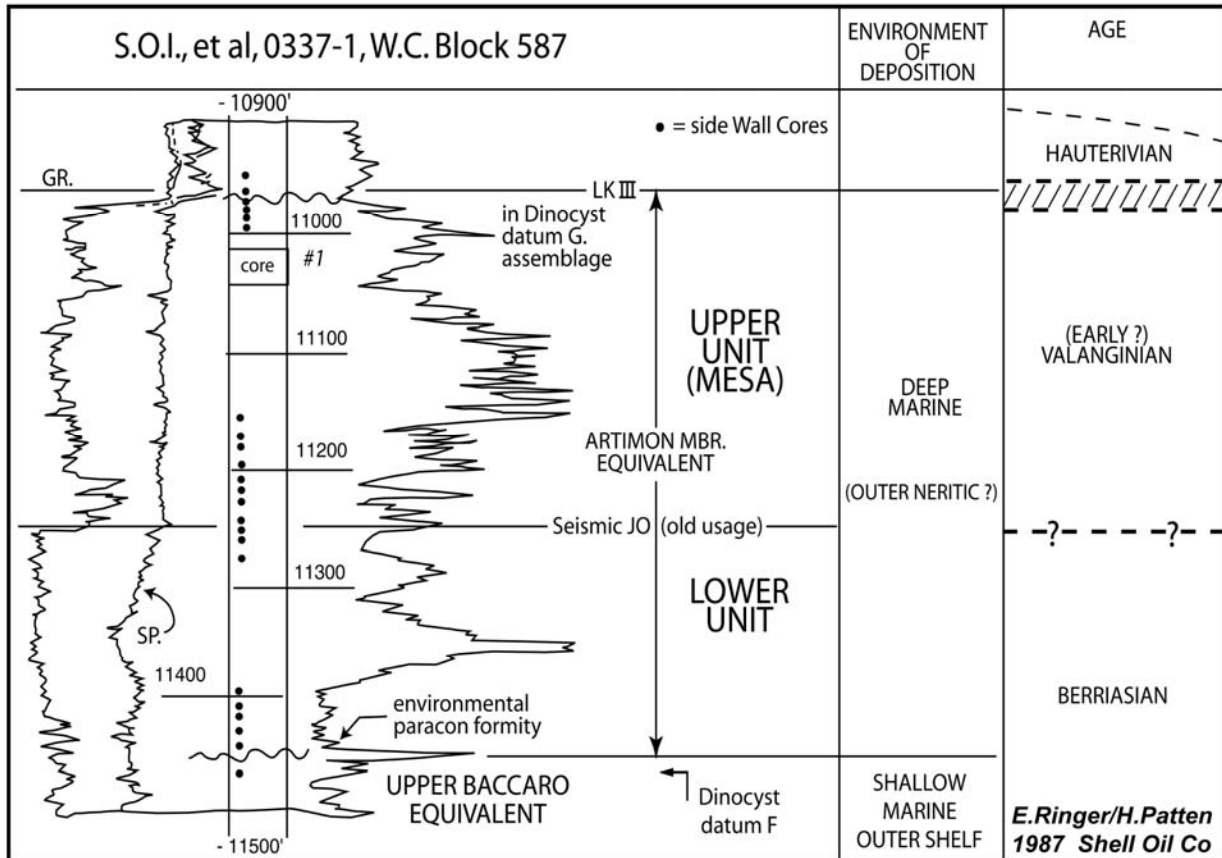


Figure 9. Annotated mechanical log of the most complete section of the uppermost Abenaki Formation, Artimon Member equivalent noted in the Baltimore Canyon Basin and as penetrated by the S.O.I.et al. OCS-A 0337-1 well.

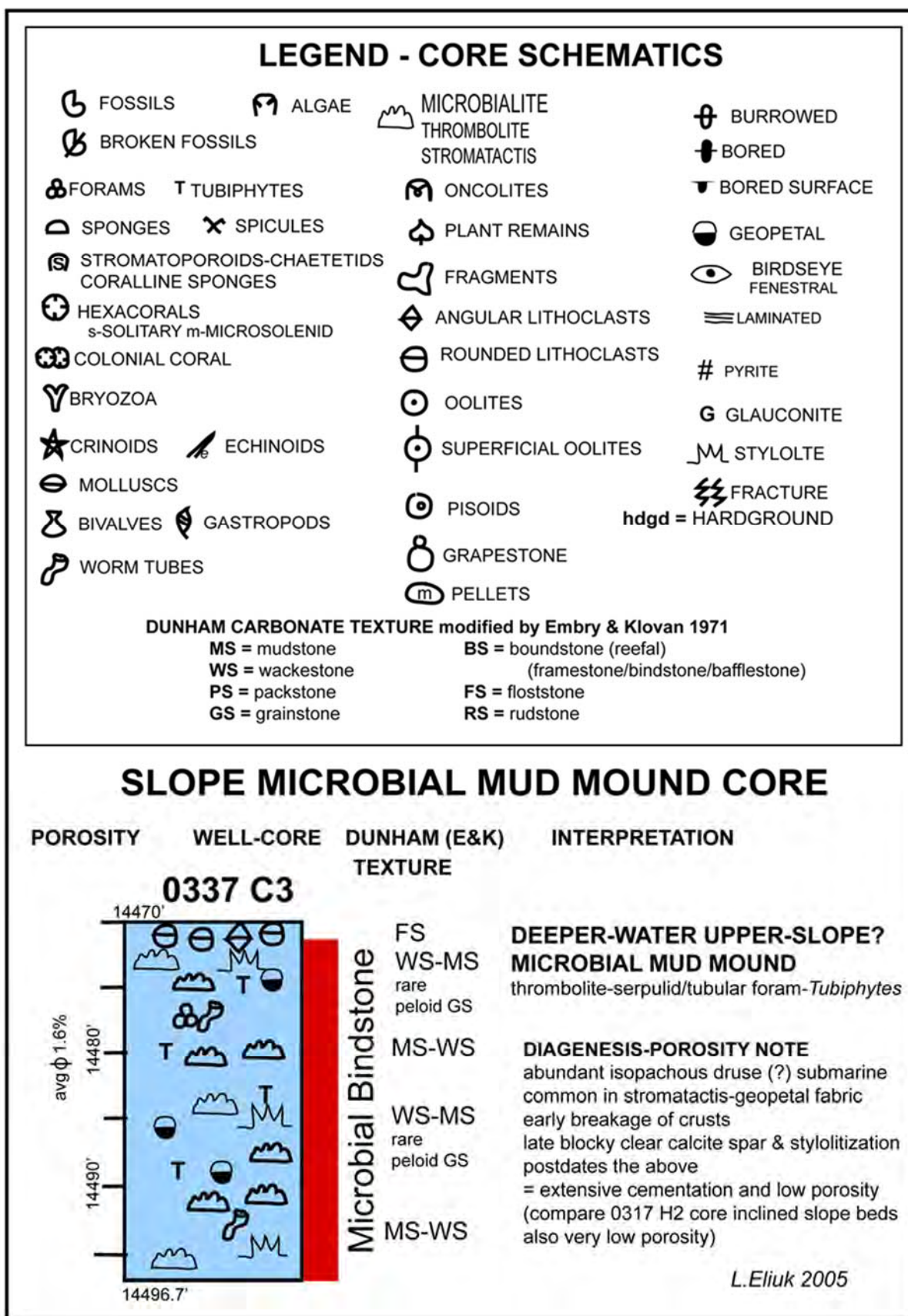


Figure 10. Core symbol legend and schematic of slope microbial mud mound core in OCS-A 0336 (C3)



SLOPE MICROBIAL MUD MOUND CORE PHOTOS OCS-A 0337 Core #3 (C3)



Lithoclast floatstone of early cemented broken microbial crusts, some clast edges bioeroded possibly when hardground. White tiny fossils typically *Tubiphytes*.



Isopachous fibrous cavity-lining ?submarine cement since has pre- and post-cement lime mud and peloid packstone geopetal fills. Tubular foram-serpulid part of wall lining and infill. Late blocky spar occlusion.



Thrombolitic textures with plentiful shelter cavities and geopetal fill (stromatactid fabric), tubular forams -serpulids (nubeculinellids?) part of micritic linings of cavities



Early fracturing of mud crusts (hardground?) or large geopetal fills overlain by lime mud to peloid wackestone with thrombolitic texture.



Highly stylolitic (horsetail) intervals common but often adjacent to thrombolitic-stromatactid early ?cemented lime mud

CORE SLABS ~ 7.5cm WIDE BAR = 1cm

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

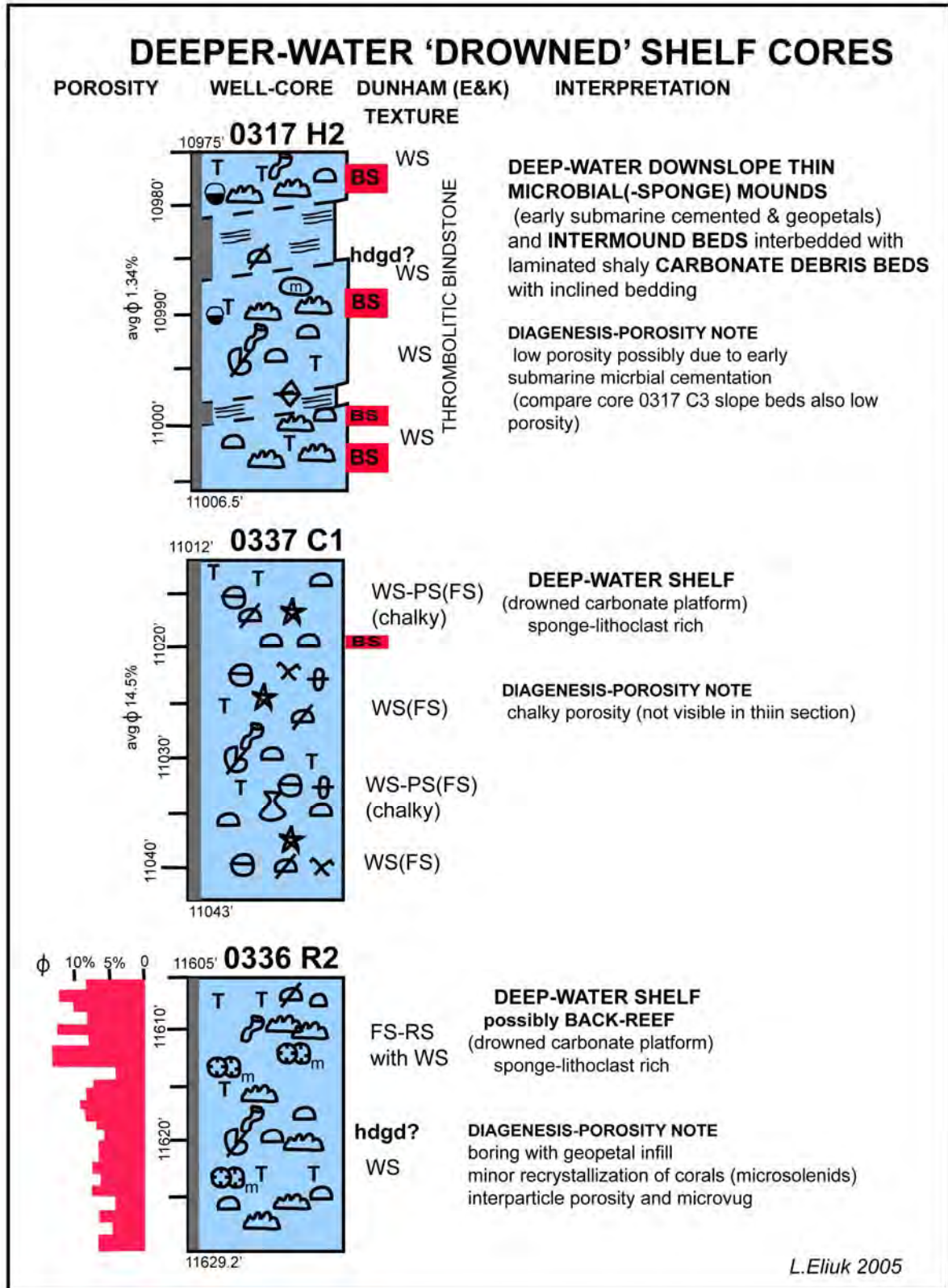
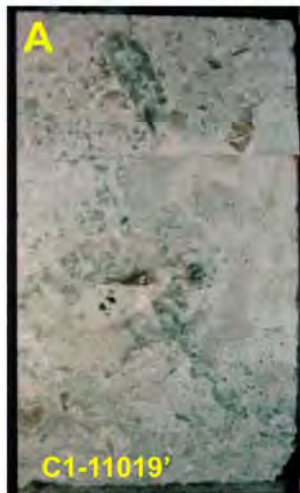


Figure 12. Schematic of deeper-water 'drowned' shelf cores in OCS-A 0317 (H2), OCS-A 0337 (C1), and OCS-A 0336 (R2).



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).

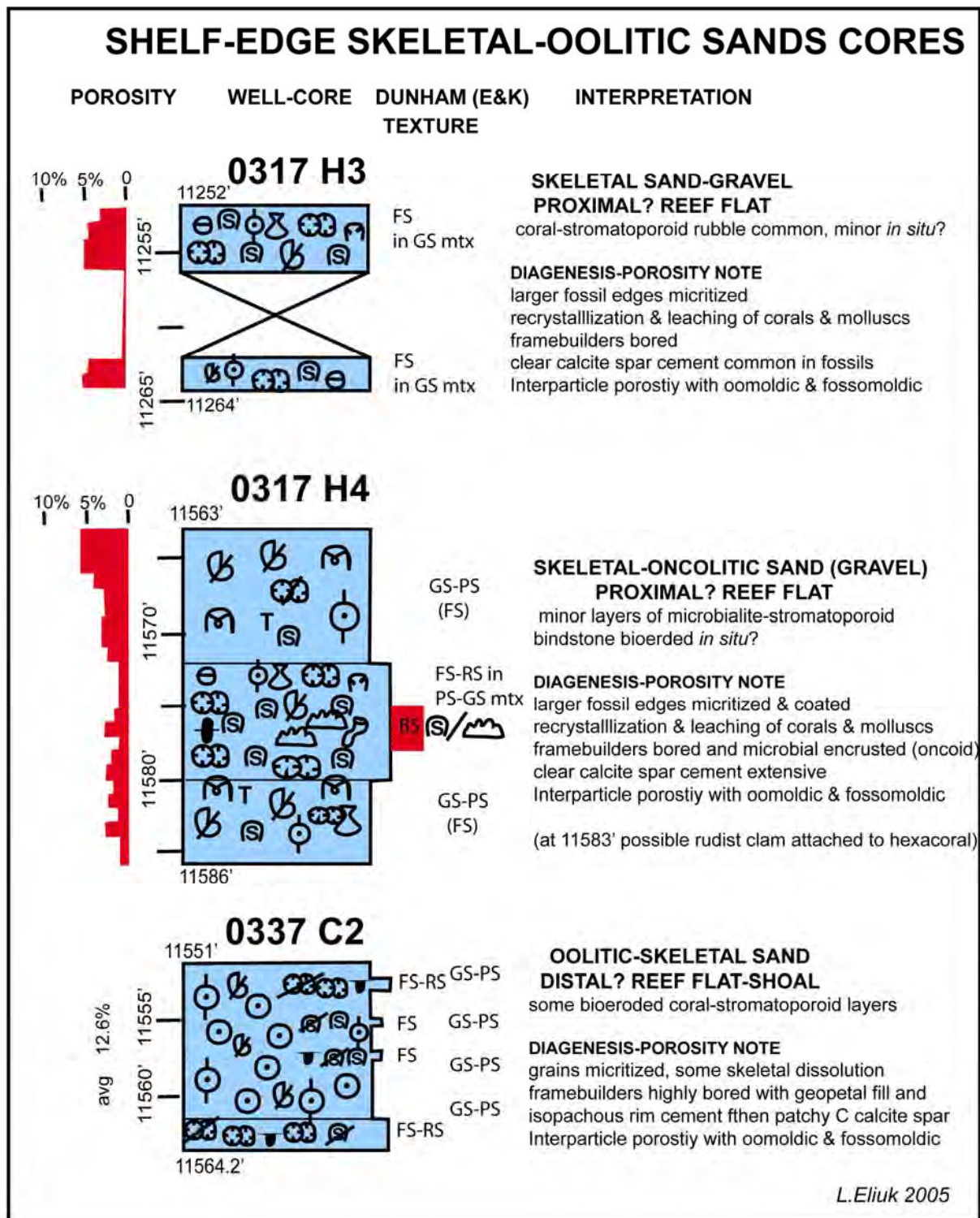


Figure 14. Schematic of shelf-edge oolitic-skeletal ‘sands’ cores in OCS-A 0317 (H3, H4)), OCS-A 0337 (C2).



SHELF-EDGE SKELETAL-OOLITIC SANDS CORE PHOTOS OCS-A 0337 Core #2 (C2) & OCS-A 0317 Core #3 (H3) & #4 (H4)



A- angular bioeroded stromatoporoid (cream) & microbial? clasts in skeletal-fragmental grainstone-packstone

D- biolithite consortia of microbialite & stromatoporoid & ?foram partially bioeroded with geopetal internal sediment



B- recrystallized (leached?) hexacoral clast with sediment filled borings in micritized skeletal-fragmental superficial ooid grainstone

E- biolithite consortia of dark ?hexacoral-bioeroded (clam borings) stromatoporoid-microbialite? capped by dense ?solenopod (red alga) overlain by skeletal-fragmental GS-PS with tubular forams-*Tubiphytes*



C- bored tabular hexacoral clasts in oolitic-fragmental grainstone

F- bored hexacoral? clast (dark) above attached to multi-layered mollusk? with cellular wall structure suggestive of rudistid bivalve (white and dark semicircular fossil ~ 10 mm across) in skeletal-oolitic grainstone



CORE SLABS ~ 7.5cm WIDE BAR = 1cm SMALLEST RULER DIVISION = 1mm

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

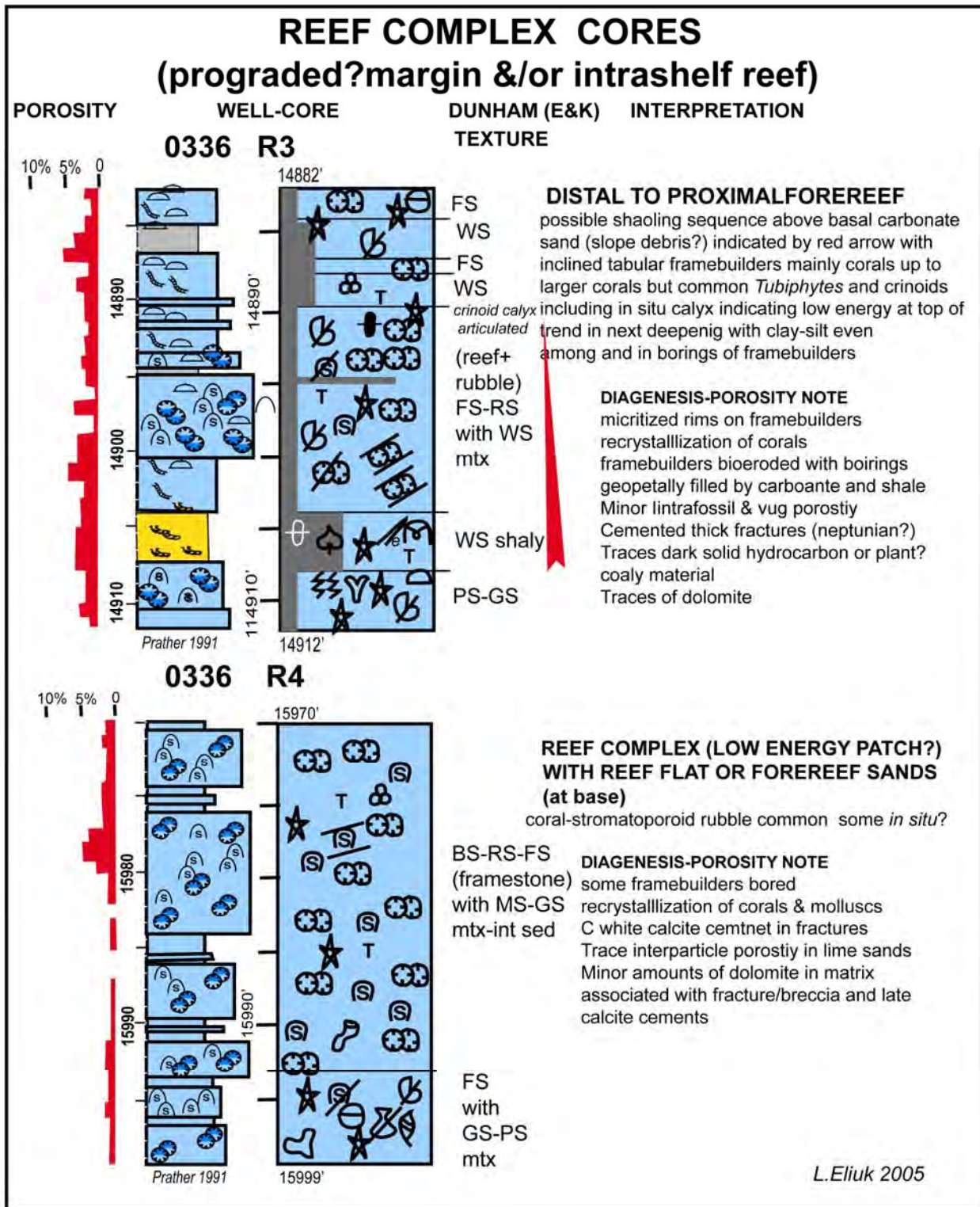
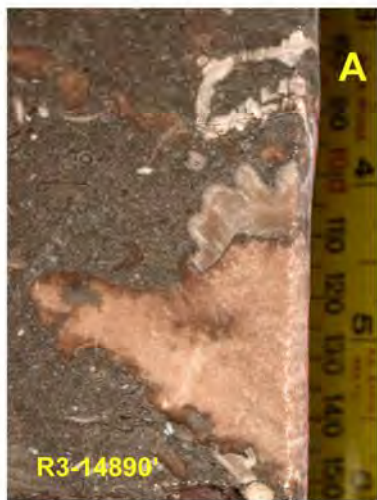


Figure 16. Schematic of reef complex cores (prograded margin &/or intrashelf reefs) cores in OCS-A 0336 (R3, R4)



REEF COMPLEX CORES PHOTOS (prograded?margin &/or intrashelf reef)



A- crinoid calyx squashed but articulated attached to underlying framebuilder that colonized a recrystallized coral clast

D- Recrystallized (?leached??) large head coral. Note late dolomite in fractured/brecciated matrix with calcite cement lining



B- tabular hexacorals possibly indicating forereef slope angle

E- branching and massive coralline sponges (stromatoporoids) in reef framestone



C- crinoid-tubiphytes-fragmental grainstone cut by XC calcite cemented fracture - terminates upward in shale



F- very large crinoid ossicles among stromatopoid & corals clasts

G- recrystallized large gastropod-bivalve fragments among reef debris and oncoids(?)



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

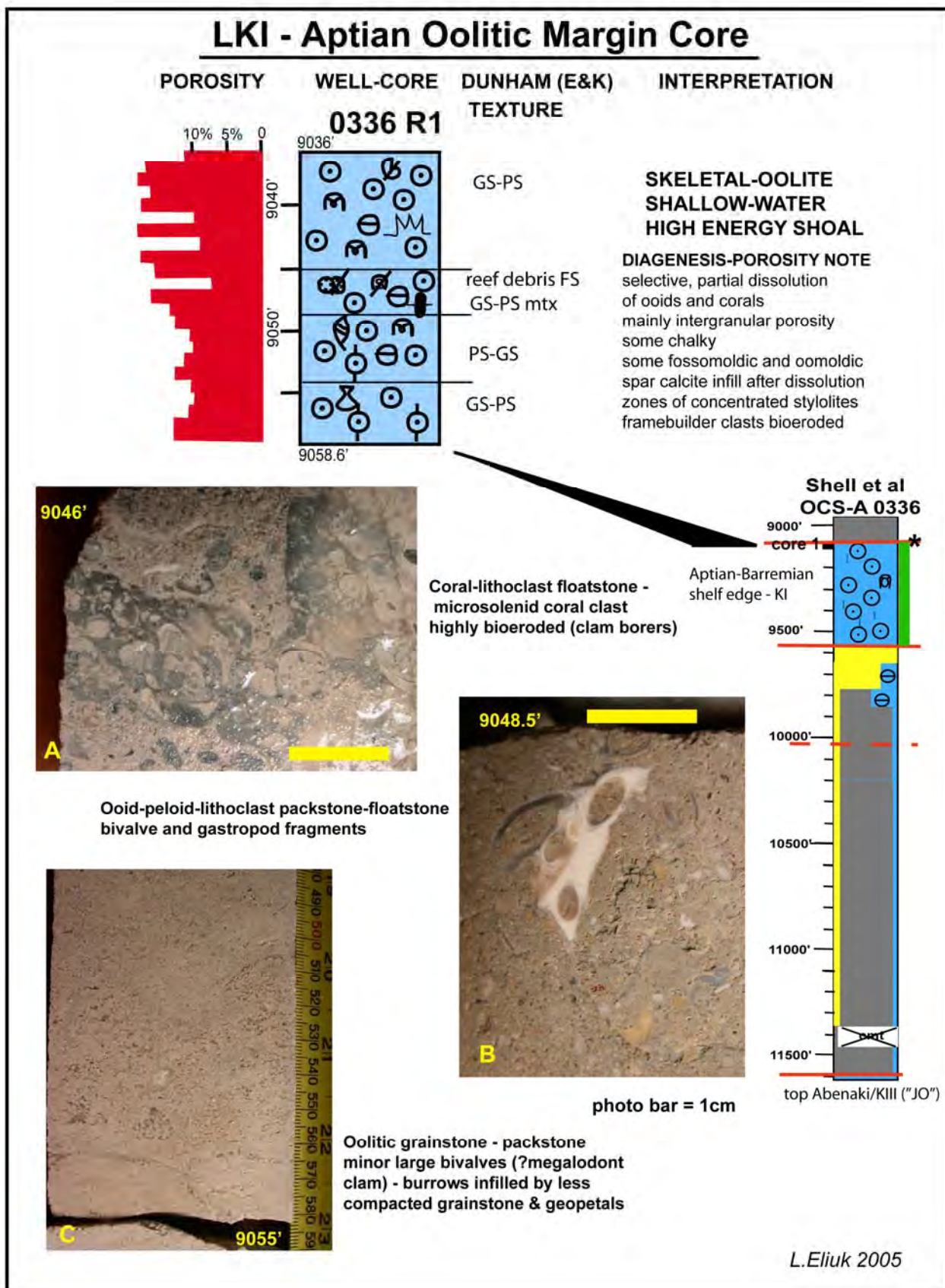


Figure 18. Schematic of Aptian oolitic margin core in OCS-A 0336 (R1).



THIN CARBONATES IN THICK SILICICLASTIC SUCCESSIONS: A USEFUL KEY TO DEPOSITIONAL ENVIRONMENTS, SEQUENCE BREAKS, AND GEOLOGICAL HISTORY – TWO CORE EXAMPLES (SOUTH DESBARRES O-76 AND WEST VENTURE C-62 #9 LIMESTONE) FROM THE JURASSIC-CRETACEOUS OFFSHORE NOVA SCOTIA

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Abstract

(Also see Eliuk's 2018 following core presentation and his talk extended abstract figures and text)

Paleogeography and climate make Mesozoic and Recent carbonates rare in Canada. High sediment supply with resulting inimical conditions make carbonates very rare in deltas. Yet during the Jurassic-earliest Cretaceous, offshore Nova Scotia had Canada's only large Mesozoic carbonate platform, and also a thick extensive continental-scale delta with rare thin limestones. Limestones in dominantly terrigenous depositional environments can have a variety of origins. As sediment mainly resulting from in situ biological processes ('borne not made'), carbonates can be sensitive indicators of their depositional setting. As such they have great potential often overlooked to aid in the interpretation of the depositional environment and geological history of the associated siliciclastics. Two thin carbonate examples in core within the Sable Delta illustrate this potential. Cores at the base of West Venture C-62 sample a shelf-margin delta complex (Cummings and Arnott, 2005) and bottom in the #9 Limestone that defines base of the Missisauga Formation (Berriasian to Barremian). Rather than a condensed unfossiliferous mudstone as once interpreted, the limestone showed a series of facies changes vertically from *Zoophycus*-burrowed marl through microbial mound into a bored deep-water sponge-microsolenid coral-red algal reef capped by a pyritized hardground and buried in prodelta mud. Since these shoaling changes occurred over just 10 m, they support the idea of a major relative sea level fall (forced regression) that Cummings and Arnott (2005) suggested for other reasons. The other example is core from South Desbarres O-76 that has thicker limestone beds formed on ramps lateral to the delta during delta switching with lithologies only seen in cuttings. However within coarse terrigenous sediments logged as channels (Gould et al. 2011, 2012) there are transported sponge and bryoderm sediments that elsewhere occur in reddened shales and an in situ bioeroded multi-coral reeflet. These show minor varied organic growth and times of non-deposition in channels from fossil communities of different origins and depths.

Introduction

Siliciclastics dominate the Canadian Mesozoic and carbonates are rare. Recent Canadian carbonates are rarer yet, but they do exist. In a review for the Canadian Reef Inventory Project (Eliuk 1988a) resulting in CSPG Memoir 13 on Canadian reefs (Geldsetzer et al. 1988), significant reefal carbonates were recognized only in the Triassic of the Canadian Cordillera and in the Jurassic-earliest Cretaceous of offshore Nova Scotia. Off Nova Scotia at that time a continental scale delta existed in the Sable Island area and excluded carbonates for the most part even though thick, often oolitic, carbonates did occur to the northeast interbedded with even thicker siliciclastics and southwest of the delta as a nearly solely carbonate platform. Nevertheless, some thin carbonates do occur within the Sable Delta. Two examples of thin carbonates, one less than a metre and the other a few tens of metres, are taken to illustrate the nature of these typically unusual inhabitants of the siliciclastic realm and also their possible



usefulness in aiding interpretation even though they often seem to be overlooked by those interested in the thick and dominant sands and shales. In an attempt to increase the number of examples of Mesozoic carbonates, Eliuk (1988a) used the term ‘atypical reefs’ in the clastic rich central cratonic area but these were found to be not so acceptable in the carbonate realm by many students of reefs. ‘Atypical reefs’ and carbonate accumulations included the following: tufas/travertines, lacustrine stromatolites and oncolites, marine peritidal stromatolites, oyster banks, shell bank/channel coquinas, sponge mounds, deep-water coral banks/thickets, and serpulid mounds. Other carbonates which were not considered are oolites, marls and chalks. Recent Canadian deposits that could serve as examples and analogues may include temperate climate carbonates of the “foramol” association consisting of foraminifera, bryozoans, barnacles and mollusks (especially bivalves; on Scott shelf off Vancouver Island and elsewhere); oyster banks (off Prince Edward Island); red coralline algal microbiostromes and rhodoliths (on East Coast); deep sponge mounds (some under ice! others in front of the Fraser delta); deep coral banks (off the East Coast); hydrothermal vent or seep-associated tube worm-clam communities (off Juan da Fuca and Pacific coast); and non-marine groundwater-associated tufa deposits (including a petrified beaver dam, Eliuk 1997) and lacustrine stromatolites in both arid and humid climates. To this list that was biased to temperate and cool climates could be added lower latitude carbonates such as coral reefs that can exist in terrigenous settings for short periods of clearer waters as during initial transgressions or with favourable clearing by currents.

Of what significance and interest to students of siliciclastics are these rare and typically thin carbonate deposits that might make them worthy of study? (1) Though rare, they are highly facies-specific for certain tidal or shelf settings, for example, estuarine or lagoonal oyster reefs. (2) They are indicative of slow or non-deposition and thus record low sediment supply and/or interdeltaic and/or bypass situations which in turn may indicate early structure such as might occur over a salt dome. (3) Alternatively, they may be indicative of sequence breaks in marine settings and associated (or subsequent) high sea-level stands with low sediment input. Tufas, like caliche carbonate soil profiles, indicate subaerial sequence breaks. (4) They, as coquinas, may provide evidence of temperate/cold or arid climates, both by resulting from low sediment supply and by not being leached subsequently. (5) Surprisingly, they may also be direct indicators of hydrocarbon accumulations. Methane in seeps forms the food base of certain Recent worm tube-clam communities and apparently was also the basis of a serpulid mound in the Cretaceous of the Canadian Arctic Islands. In discussing these ‘atypical reefs’ and deposits at this core workshop I wish to foster an appreciation for such carbonates in those who will be examining the surrounding terrigenous sediments. Three decades ago Eliuk (1988b) asked for help in reporting any examples of such deposits. The response was underwhelming. So here I try again but I may not have 30 years for a response. One exception was Taylor et al.’s (2002) article on iron oolites or coated ironstones in the Cretaceous western interior seaway of Alberta and Utah. That as a bioelemental sediment (Pufahl 2010) was close to be a carbonate. And the east coast top carbonates have a number of layers of thin marine coated ironstones that capped the Abenaki Formation on the Western Shelf. A cored example of these slowly deposited seafloor accumulations are displayed with my other presentation at this core workshop. Eventually we may all get a better understanding of these potentially highly useful and interesting but rare carbonates that occur in default of high or even moderate siliciclastic sedimentation.

The wells occur within the Sable Delta as shown on **Figure 1**. West Venture C-62 is part of a gas field in a shelf margin delta. South Desbarres O-76 is also in the main part of the Sable Island Delta complex but at times had carbonate ramps with both topset shallow oolitic carbonates and foreset slope microbial carbonates. These likely developed during episodes of delta switching during the long-continued seaward progradation of the Sable delta. The thin carbonates shown in core 1 and 2 in that well occur during deltaic sedimentation in the upper portion of



the Jurassic aged delta. A deeper core 3 occurs near the base of the well and shows laminated fabric but likely in deep water.

West Venture C-62 and Nearby Venture Wells – Deltaic Limestones
– Minor Thin Limestones of the #9 Limestone in the Late Jurassic Sable Delta
(Excerpted from Eliuk 2016)

The limestone occurs at the base of a long number of terrigenous deltaic cores as shown in **Figure 2D**. The #9 Limestone Marker at top MicMac Formation in Mobil West Venture C-62 represents the thin end-member of a spectrum of Abenaki-equivalent limestones. This core and nearby offsetting well cuttings (**Figure 2A-2C**) show that limestone can occur within the Sable Delta itself, albeit thin and certainly nothing like a carbonate platform or even the generally thicker limestones occurring on the ramps flanking the delta. The details from the limestone give major insight to the associated terrigenous sediments. The C-62 core has several vertical facies changes that can be interpreted to result from shoaling and/or reduced turbidity, only to be abruptly terminated then followed by prodeltaic shale deposition. **Figure 3** shows schematically the facies changes (**numbered**) in the #9 Limestone at the base of a long series of C-62 cores. The main lower facies are very argillaceous limestone to calcareous shale or marl that can be subdivided into a **(1)** highly bioturbated lower interval lacking in body fossils with a great number and variety of ichnofossils including *Zoophycos* indicating an oxic deep shelf/upper slope environment. That is overlain by **(2)** a depauperate massive marl to argillaceous micro-packstone. Then **(3)** an encrusted debris bed forms a substrate for **(4)** a pure microbolite (thrombolitic) mound with a limited variety of micro-encrusters (*Tubiphytes*, serpulids, nubeculinellids). This grades upward with increasing *in situ* skeletal content to **(5)** a microbial-microsolenid coral-lithistid sponge-red algal (?solenopodid) reef mound suffering some bioerosion (mainly clam borings). That is abruptly overlain across a pyritized hard ground(?) by **(6)** dark laminated prodeltaic shales or clay mudstones with some ironstone cemented layers and thin beds of siltstone to fine sandstone that become burrowed and more common upward. These subfacies are illustrated in a series of following figures (**Figures 4 to 10** and described in more detail in at the end from Eliuk 2016). What had previously been interpreted in the West Venture C-62 core as condensed lime mudstone without framebuilders (Cummings and Arnott 2005; Gould et al. 2012 also examined this core but did not include this limestone), in fact had a succession of mound and reef facies that changes over just 9m vertically before being buried by prodeltaic shale. **Figure 2D** labels the #9 Limestone main lithologies seen in cuttings and core from five wells of a few samples over a thickness of 7 to 40 metres. Oolite and possible reefal beds of lithistid sponges-stromatoporoids (coralline sponge)- corals are the two main lithologies with marls and skeletal-fragmental-pelletal wackestones as well. Although oolite can be transported from its place of deposition, it is fairly obvious that the West Venture C-62 core along with N-91 cuttings were deposited in less agitated (deeper) water than the wells to the east which seem to be part of a thin oolite shoal complex. The widespread but differing nature of Abenaki or equivalent limestones and their utility even when very thin for giving depositional information is given a more comprehensive treatment in Eliuk (2016 Section 5.2.1) where they are divided into upper and lower units (**Figure 2A and 2B**). There this limestone will be put in context of the Late Jurassic Sable Delta in the Venture gas field and provide support from a very different perspective for Cummings and Arnott (2005) shelf margin delta and forced regression interpretations. **Figure 11** summarizes that analysis where the carbonates support Cummings and Arnott's idea of a relative sea level fall as their forced regression by the shoaling nature of the organic communities over a much too limited thickness to be explained by "growing" up into the light of shallow water. And the 'cleanness' of the limestones particularly the fact the



shallowest limestone actually gets slightly more argillaceous argues against the idea that reduced turbidity explains the community changes.

South Desbarres O-76 – Distal Ramp Well

- Smallest Coral Reeflet, Bryoderm Transgressive Markers

(Excerpted with modification from Eliuk 2016)

Shell South Desbarres O-76 unsuccessfully tested a roll-over anticline between two normal-growth faults. As reviewed in (Eliuk 2016 Section 4.02), seismic geometries in O-76 are similar to those in Penobscot L-30 with topset and foreset reflector limestones but over 8 km and several prograded clinoform sets basinward of a possible Abenaki platform edge, or more likely an atoll margin. Thus, these wells represent proximal (L-30) and distal (O-76) ramp examples. A schematic lithofacies log of O-76 **Figure 12B** is shown (with Penobscot L-30 plotted beside it for comparison, **Figure 12A**). Unfortunately, the seismic correlations are not obvious between the two wells and there is no new/revised dating in L-30 as discussed in the review of new age dating for the PFA study (OETR 2011,). The actual dating of the top limestones may be particularly difficult since top limestone in Marquis L-35 at the Abenaki platform margin somewhat south of this area is older than top limestone in South Desbarres O-76, suggesting that there might be renewal of carbonate sedimentation in distal ramp settings after it had terminated on the Abenaki platform margin. In both O-76 and L-30, the facies show a shoaling upward trend into the oolitic beds from reefal beds with corals and stromatoporoids which are better developed in O-76 and underlain by a bed of lithistid sponges and microsolenid corals indicating even greater depths distally. In South Desbarres O-76, bryoderm beds with one just above the last oolite but within the thick topset limestone may represent transgressive sequence breaks. In O-76 a higher thin limestone marking top MicMac (sometimes taken as top Jurassic) was rich in sponge reefal beds with cuttings greater than 10% lithistid sponges and possibly sponge mounds thus likely associated with deeper or more turbid waters. The lower thick limestone in a foreset clinoform position consisted mainly of mudstones and thrombolitic beds of a deeper-water distal slope facies. This clinoform-associated facies was cored in Penobscot L-30 and is similar to distal slope beds along the platform margin but seemingly with a more depauperate restricted biota. O-76 and L-30 foresets are unlikely to be correlative limestone given the difference in numbers of clinoforms and much greater distance from the main Abenaki edge in South Desbarres O-76. In South Desbarres O-76 cores 1 and 2 above the highest limestone beds, channel sandstones as logged by (Gould et al. 2011, 2012) with basal thin conglomerates had an extremely thin but *in situ* bioeroded coral reeflet (**Figure 13** and not shown in the GSC and published logs) with various other fossil-rich layers including lithistid sponges and crinoids bryozoans (bryoderm beds) mainly in shales that are partly reddened. Although stratigraphically in the Missisauga Formation, the cored interval was dated as Late Tithonian (Weston et al. 2012) and their NBCU placed above it at 3770 m so it is age equivalent to Abenaki. This reeflet represents the thinnest shallow-water coral reef development yet found and shows that for brief periods conditions were favorable for shallow-water bioherm development, even in deltaic to inter-deltaic siliciclastic settings.

Conclusion

Organisms abundant enough to form clean carbonates can thrive near or in tropical deltas. But they do not last long before being fouled, choked, swamped, diluted and buried by the abundant influx of siliciclastics. These two examples - one a few tens of metres forming a sub-regional marker bed and the other less than a



metre thick but an in situ mini-reeflet in a temporarily abandoned channel - are both thin and certainly thin when compared to the great thicknesses of sands and shales that enclose them. By actively growing during low sedimentation periods or sites (on salt cored highs for instance) they give disproportionately large insight on their depositional environments and history. Like the bioelemental sediments of coated ironstones or ooidal iron carbonates discussed and shown in the following presentation, these sediments are formed, or in most cases of carbonates actual grew, in situ or very near their place of deposition. Thus, they are very precise indicators of their environment as to depth, temperature, sedimentary breaks, sequence boundaries and so on. In some cases, they represent long periods of slow deposition and as mentioned it is that absence of siliciclastic dilution that usually results in their occurrence at all. While discussed separately they are the end members of the range of carbonate occurrences during the Jurassic-Cretaceous that end with kilometre thick carbonate platforms that are the topic of the following presentation. In both examples they were overlooked or poorly examined so that they originally did not yield their potential information. Such carbonates are well worth looking for and examining.

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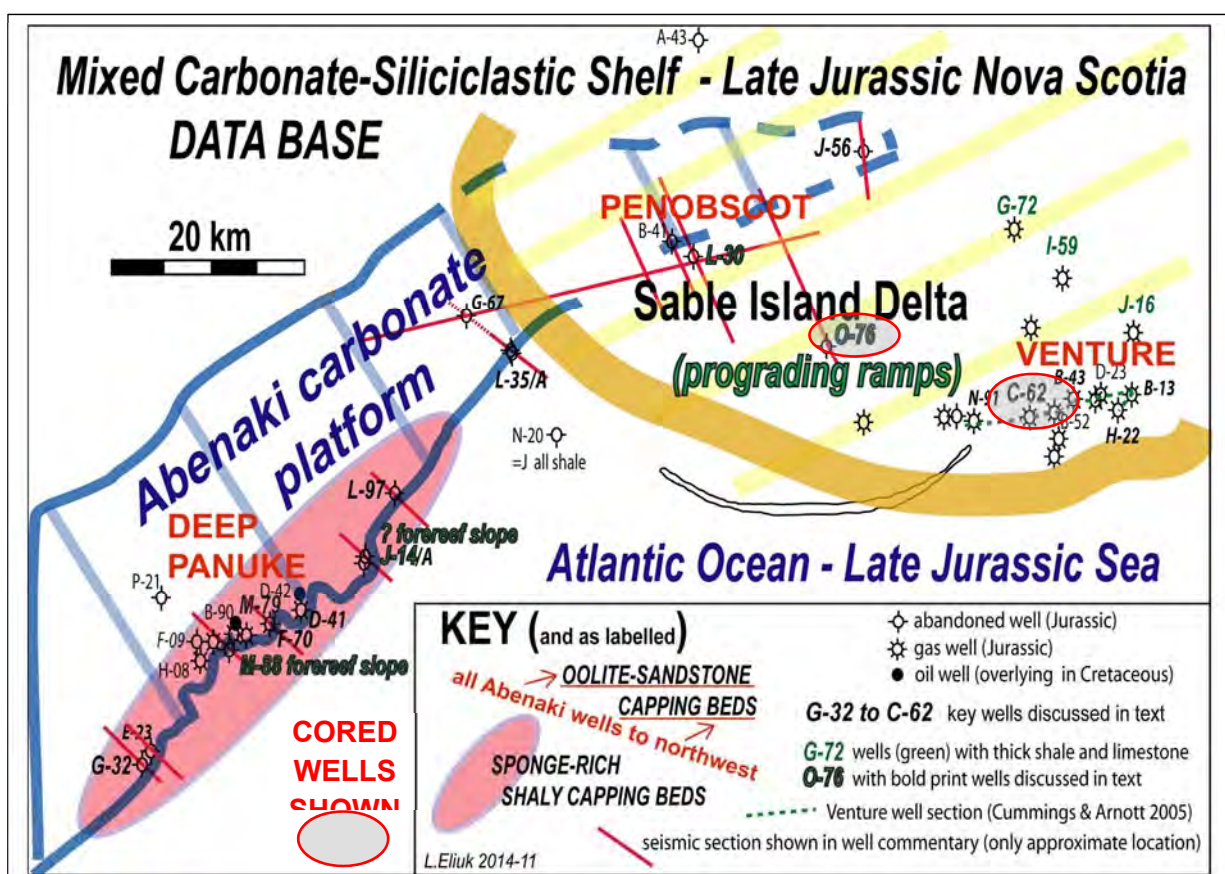


Figure 1. Location map showing contact of Sable Delta and Abenaki carbonate platform about end of Jurassic and location of wells with cores on display (indicated by ovals) . Shelf edge deltaic gas field at Venture and carbonate field at Deep Panuke are separated by Sable Island, Modified from Eliuk 2016.

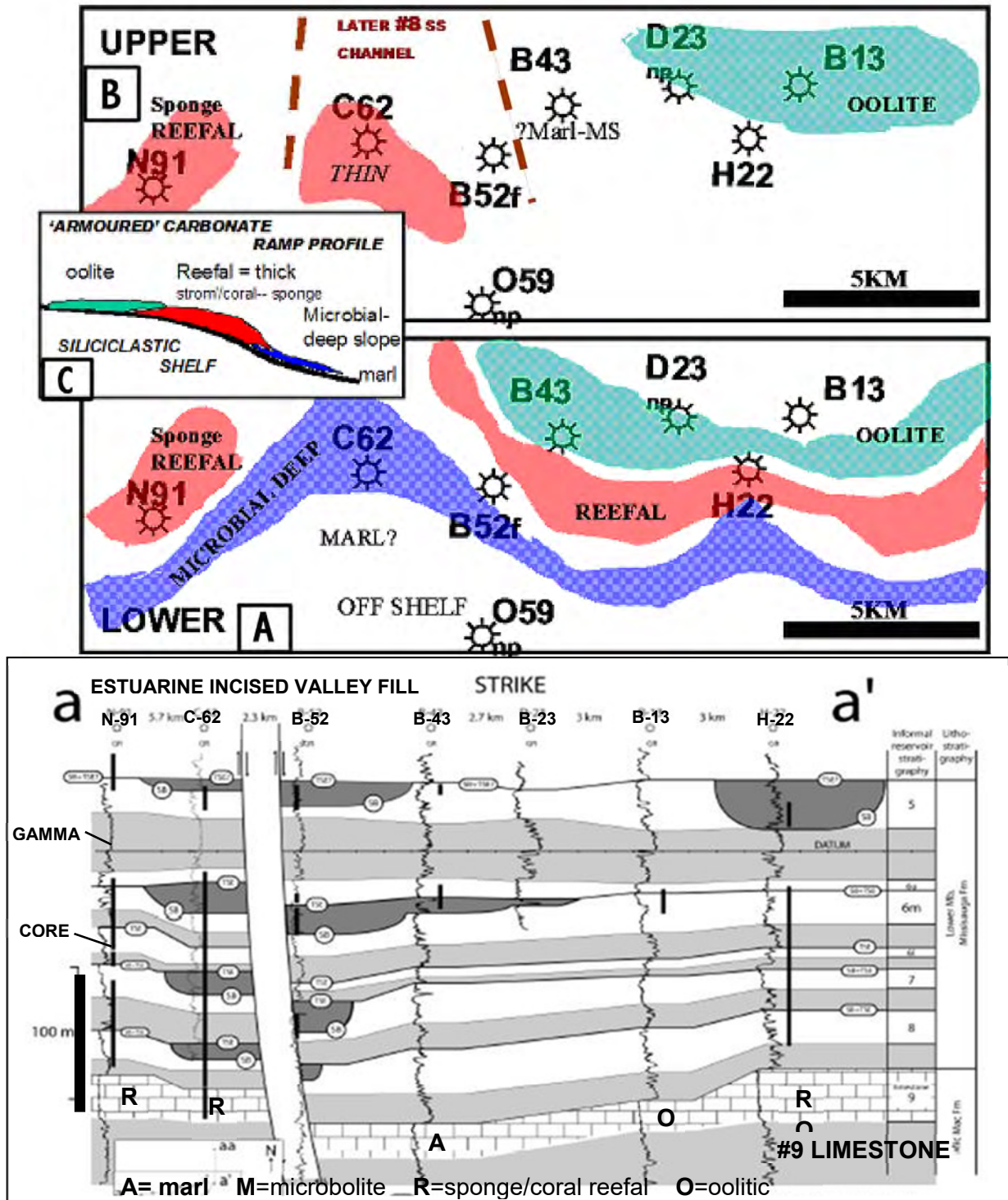


Figure 2. Venture area #9 Limestone depositional maps and strike section based on cuttings and core. A) Lower half #9 sketch map (10-20 m thick), B) Upper half #9 sketch map (10-20 m thick), C) Schematic ramp facies dip profile and D) Stratigraphic strike section (modified from Cummings and Arnott 2005, fig. 5). See Eliuk (2016) for cuttings and core lithofacies summaries for #9 Limestone and more detailed discussion of cuttings-based analysis

(Eliuk 2016 modified from Eliuk and Wach 2008, 2009)

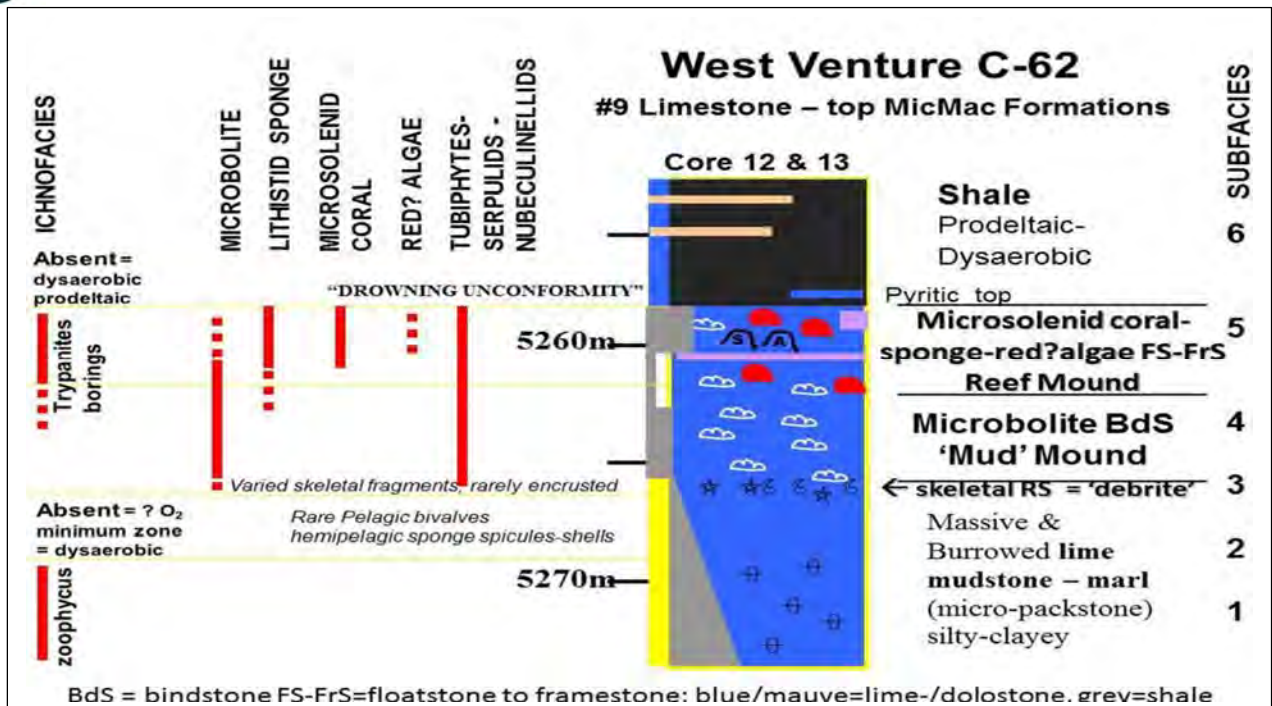


Figure 3 West Venture C-62 #9 Limestone schematic core log summary of depositional subfacies The vertical distribution of key fossils allows subfacies to be distinguished and indicate a upward shoaling.

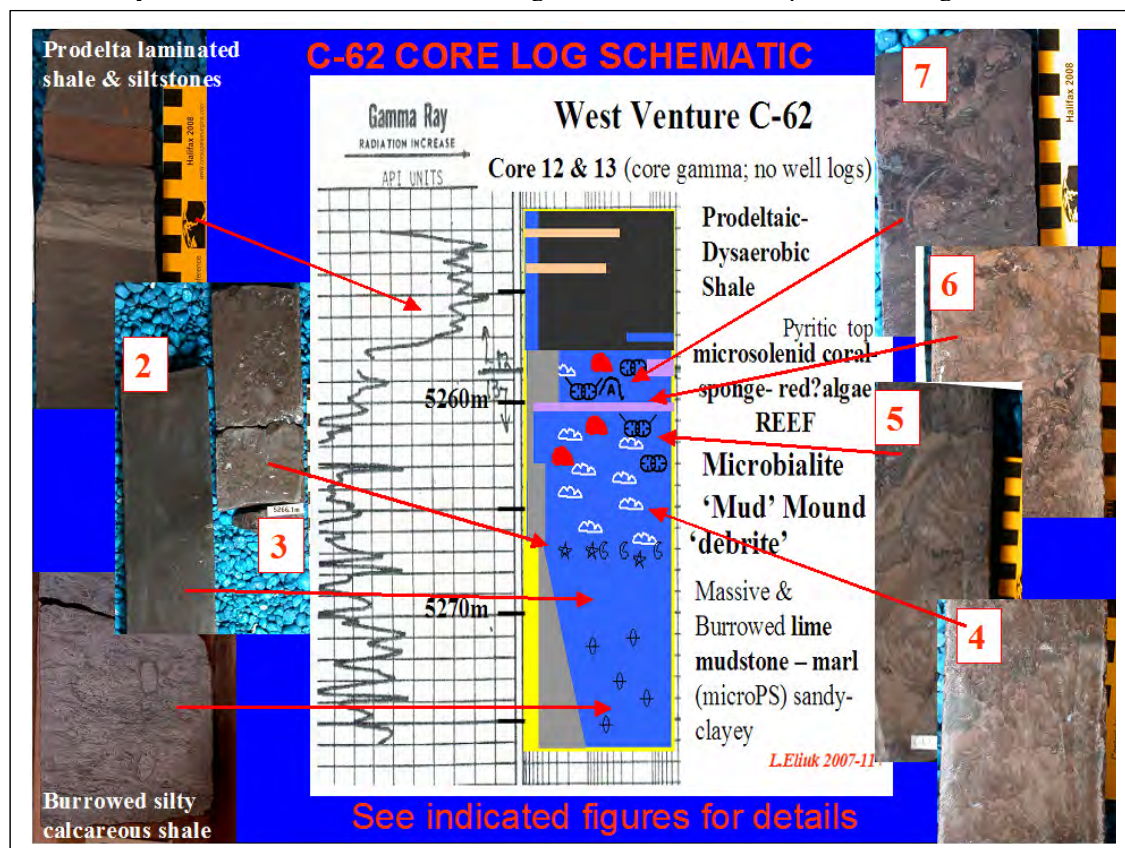
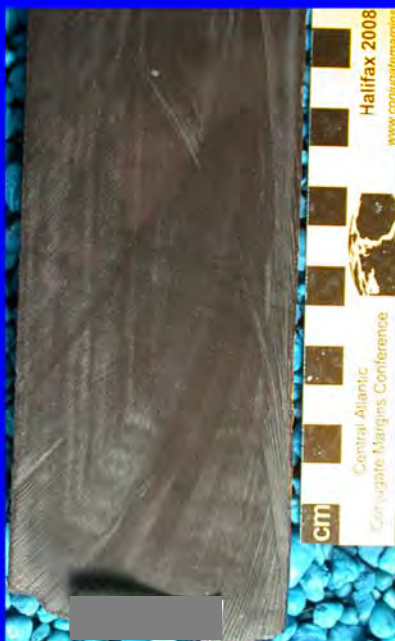


Figure 4. West Venture C-62 #9 Limestone schematic core log summary a number of facies features are illustrated in more detail in the following figures as indicated by the numbers (most symbols key to labels, purple lithology is fine crystalline dolomite, star is crinoid). No logs were run in the lower well but a core gamma indicates the relative radioactivity (indicative of argillaceous content or 'clean-dirty' (Eliuk 2016))

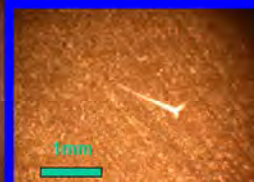


2

Marl – massive argillaceous lime mudstone (micro-packstone?)



Rare encrusted shell fragment



Sponge spicule triaxon

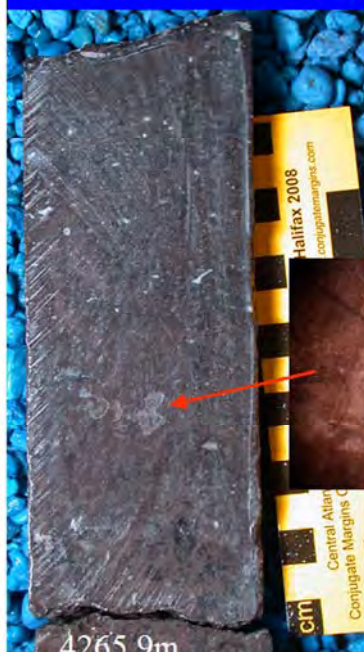


Delicate articulated bivalves & sponge spicules (<1mm long)

Figure 5. Venture C-62 #9 Limestone core facies - 2 massive marl-mudstone. Depth ~5269 m.

3

“Debrite” – basal Floatstone-packstone with local microbial stabilization (bindstone)



Tubiphytes
Fragments –
bryozoan
sponges
microsolonid
coral



‘white’ sponge



Local microbialite colonization with geopetals

Figure 6. Venture C-62 #9 Limestone core facies - 3 debris bed. See longer caption below

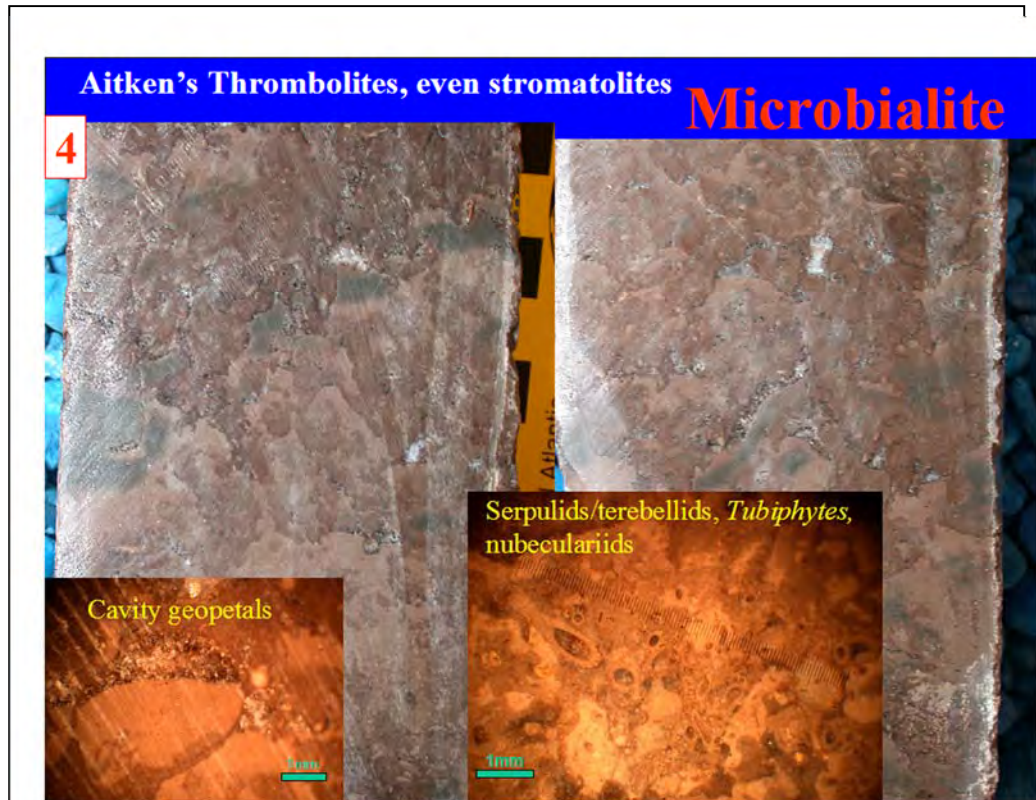


Figure 7. Venture C-62 #9 Limestone core facies -4 microbialite

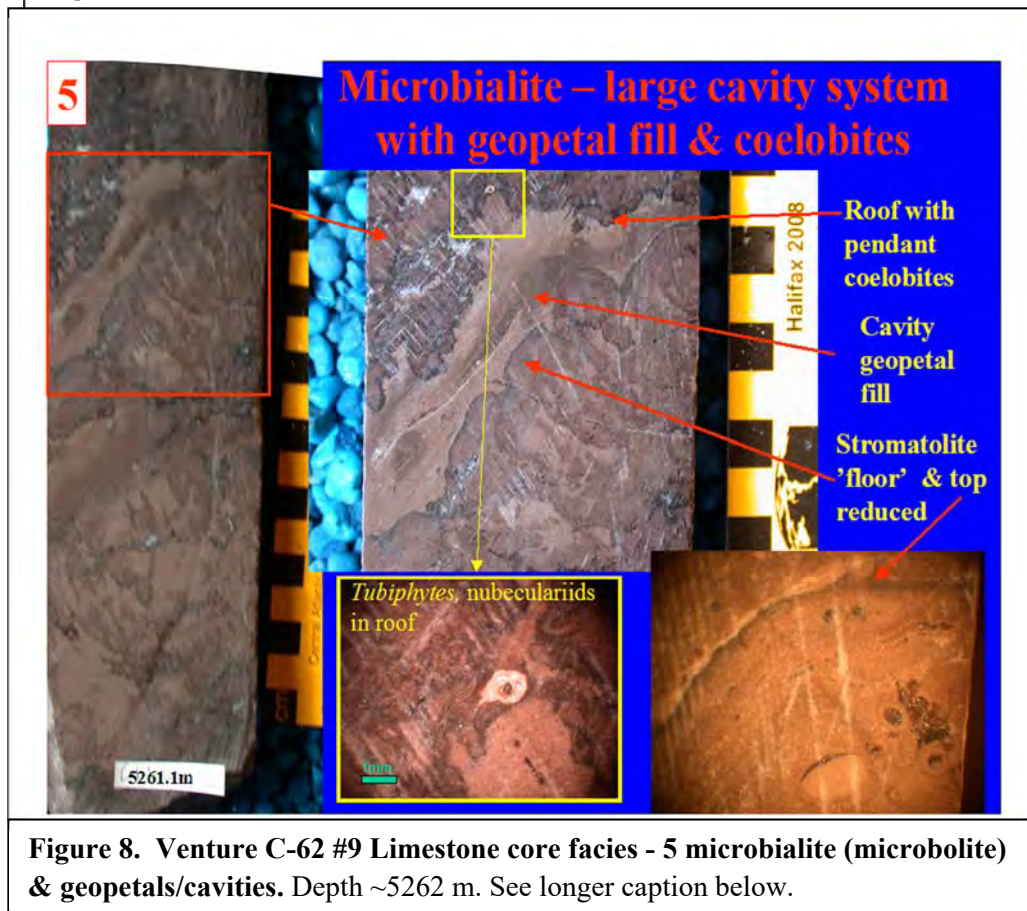
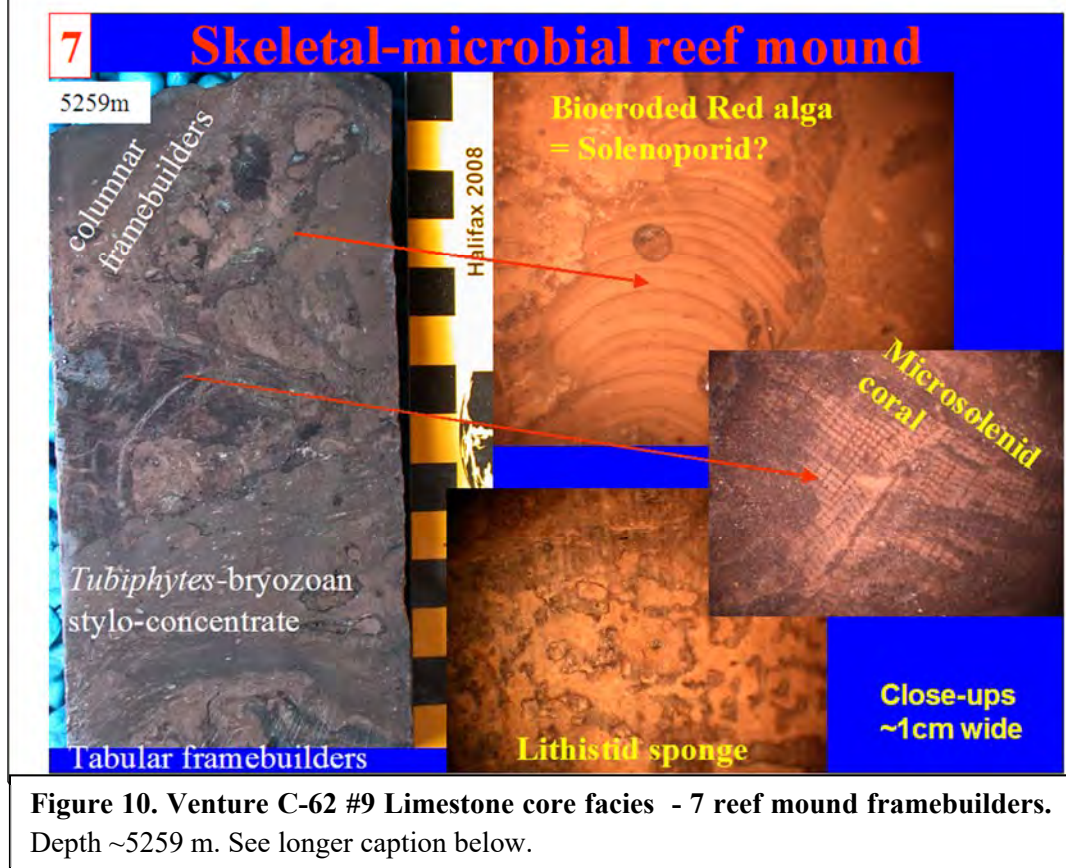
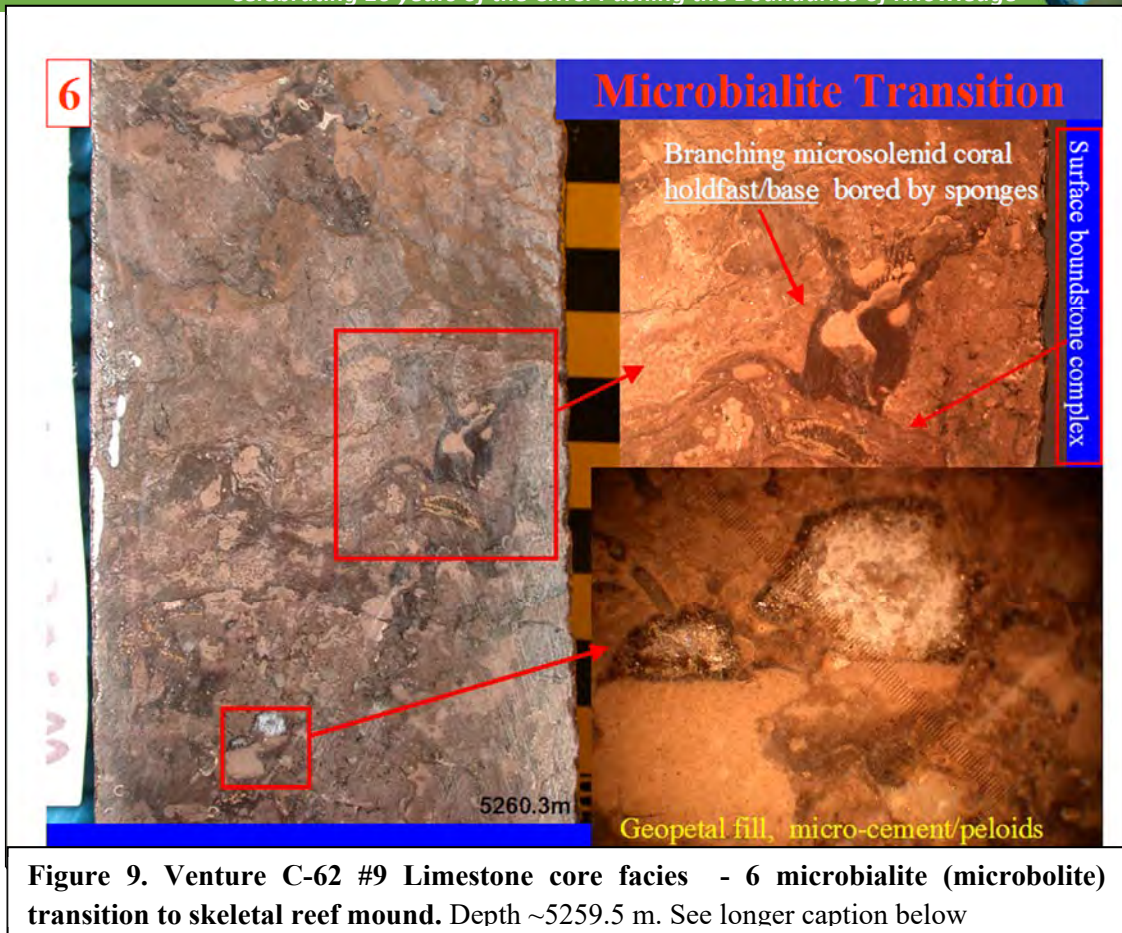


Figure 8. Venture C-62 #9 Limestone core facies - 5 microbialite (microbolite) & geopetals/cavities. Depth ~5262 m. See longer caption below.





Detailed Figure Captions for Figures 5 To 10.

Figure 5. West Venture C-62 #9 Limestone: marl –massive argillaceous lime mudstone to micro-packstone – this massive-appearing argillaceous limestone is composed of sublithographic to fine particles with only a few larger fossils hence the lime mudstone to micro-packstone designation. Some of the fine fragments appear angular and might be scallops from sponge bioerosion of shallower reefal beds and skeletons. Those few fossils are small and include crinoid ossicles, sponge spicules and small bivalve shells. One disarticulated bivalve was microbially coated but the few others were not encrusted and still articulated showing a lack of energy or even bioturbation and possibly originated from a nektonic mode of life. Therefore the lack of lamination is not thought to be due to burrowing but represents the original texture perhaps due to a ‘soupy’ nature or rapid sedimentation. The carbonate sediment is interpreted to be winnowed from carbonate shoals diluting the low amount of clays coming during near maximum flooding.

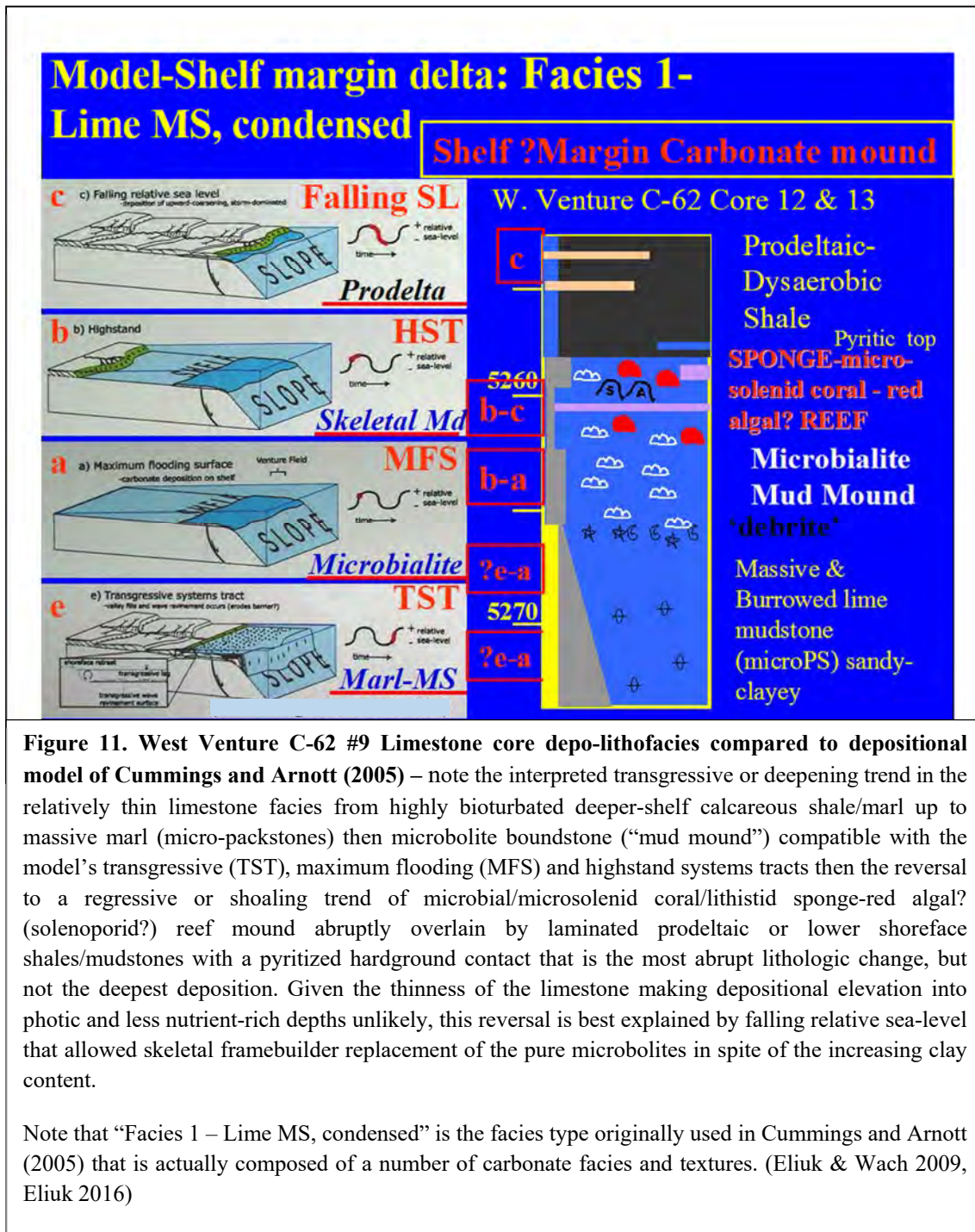
Figure 6. West Venture C-62 #9 Limestone: skeletal packstone to floatstone debris bed (about 3 decimetres) with microbial stabilization – a great variety of small fossil fragments mostly deeper? heterozoans such as crinoids, bryozoa, *Tubiphytes*, bivalves, gastropods, brachiopods?, sponges, forams but also microsolenid corals and a possible colonial stylinid or oculinid coral. Locally there is microbial encrustation and therefore stabilization of the fossil fragments which are interpreted as storm or avalanche derived debris from shallower carbonates. The whole bed serves as a hard substrate that allows colonization by the overlying microbolite ‘mud mound’.

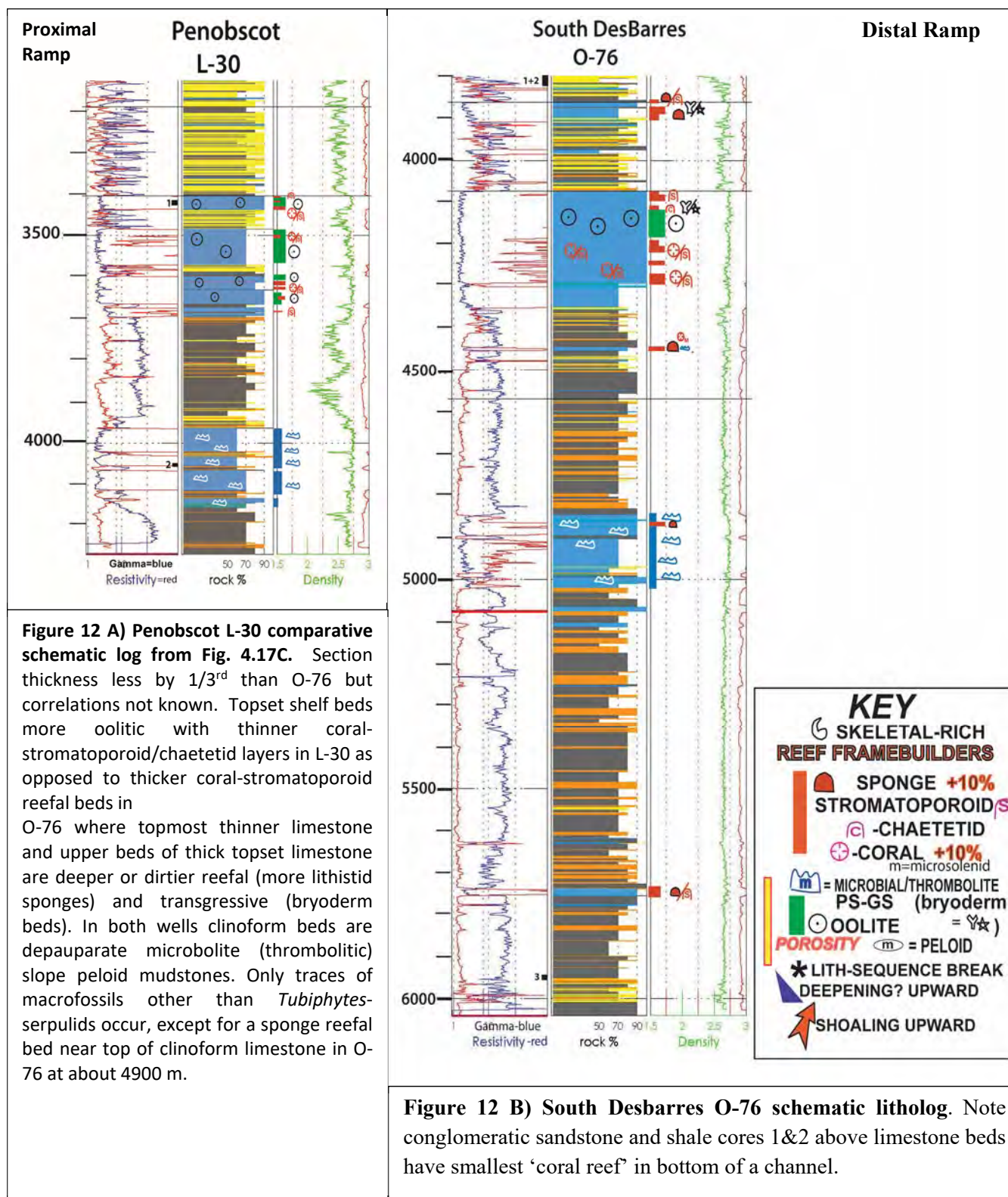
Figure 7. West Venture C-62 #9 Limestone: pure microbial boundstone with thrombolitic to stromatolitic textures and limited but plentiful micro-encrusters – about 5 m thick of peloidal to massive mudstone with numerous shelter cavities that are geopetally-filled by peloid grainstone with varied development of later calcite cements that often include a thin initial isopachous rim. The micro-encrusters occur in the mudstone but also can encrust both upper and lower microbolite surfaces. They include *Tubiphytes* (also known as *Shamovella* and possibly Jurassic foraminiferal-microbolite consortium that is characteristically in reef slope debris beds and outer ramps to deeper slopes, Flügel 2004), serpulids-terebellids-tharthalrelids (various encrusting worm tubes with some smooth-walled calcite, some agglutinated) and nubecularids (tubular foraminifera chambered and branching). (Jim Aitken coined the term ‘thrombolite’ for clotted fabrics interpreted as subtidal stromatolites in Lower Paleozoic rocks in the Southern Canadian Rockies).

Figure 8. West Venture C-62 #9 Limestone: pure microbial (microbolite) boundstone large cavity system – larger cavities of several centimeters height occur in the upper part of the microbolite interval and are filled by geopetal muds. Top and bottom surfaces appear slightly darkened grey possibly reduced (such color alteration occurs throughout the microbolite – see previous figure) and may be colonized by micro-encrusters or show pendant microbialites. Often there are bewildering gradational transitions from ‘hardened’ microbolite bindstone fabrics to geopetal infill fabrics.

Figure 9. West Venture C-62 #9 Limestone: pure microbolite to microbial-skeletal boundstone transition – over a metre or so hard microbolite bindstone surfaces are increasingly encrusted by tabular skeletal framebuilders or colonized by holdfasts or bases of branching-columnar framebuilders like this microsolenid corals with a highly bored interior (the sponge-boring *Entobia* makes the coral superficially look like the central cavity of a framework sponge!). An *in situ* lithistid sponge is left of the *in situ* dark coral column.

Figure 10. West Venture C-62 #9 Limestone: skeletal microbolite reef mound framebuilders – include lithistid and ‘white’ sponges, minor chaetetids and microsolenid corals that show complex intergrowth with each other and the microbolites. The preservation of corals due to early dissolution often makes identification problematic but it appears that only microsolenid corals with their characteristic zigzag ‘tire-track’ pattern (see Fig. 5 of Dupraz and Strasser 2002) are present. All framebuilders are relatively small with the microsolenids perhaps as common as the lithistid demosponges. Their small size and dominantly *in situ* position indicates a low energy, deeper-water probably stressed setting. The high amount of bioerosion of skeletal framebuilders (microbialites are seldom infested) by bivalves (*Gastrochaenolites*) and sponges (*Entobia*) suggest very high nutrient levels. Several occurrences of an extremely finely layered with thin dark and thick light bands is interpreted as a solenoporid (usually considered a red algae). Unfortunately the finest texture is uniformly recrystallized and the identification is not positive with less preferred alternatives of milleporid (hydrozoan cnidarian with usually a coarser cell structure than solenoporid and therefore less likely to be completely and uniformly recrystallized) or of some kind of skeletal stromatolite. In any case the argument for ameliorating and likely increasingly photic conditions for the skeletal reef mound as opposed to that of the pure microbolite is reasonable. Considering the increasing amount of argillaceous content indicated by the gamma log this is surprising unless there is significant relative sea-level fall. Although diagenesis is not the focus this bit of core does show a relatively common fabric due to high amounts of stylolitization aided by the high argillaceous content – solution seams and stylo-concentrates of refractory less soluble calcitic fossils like *Tubiphytes*-bryozoa-crinoids.





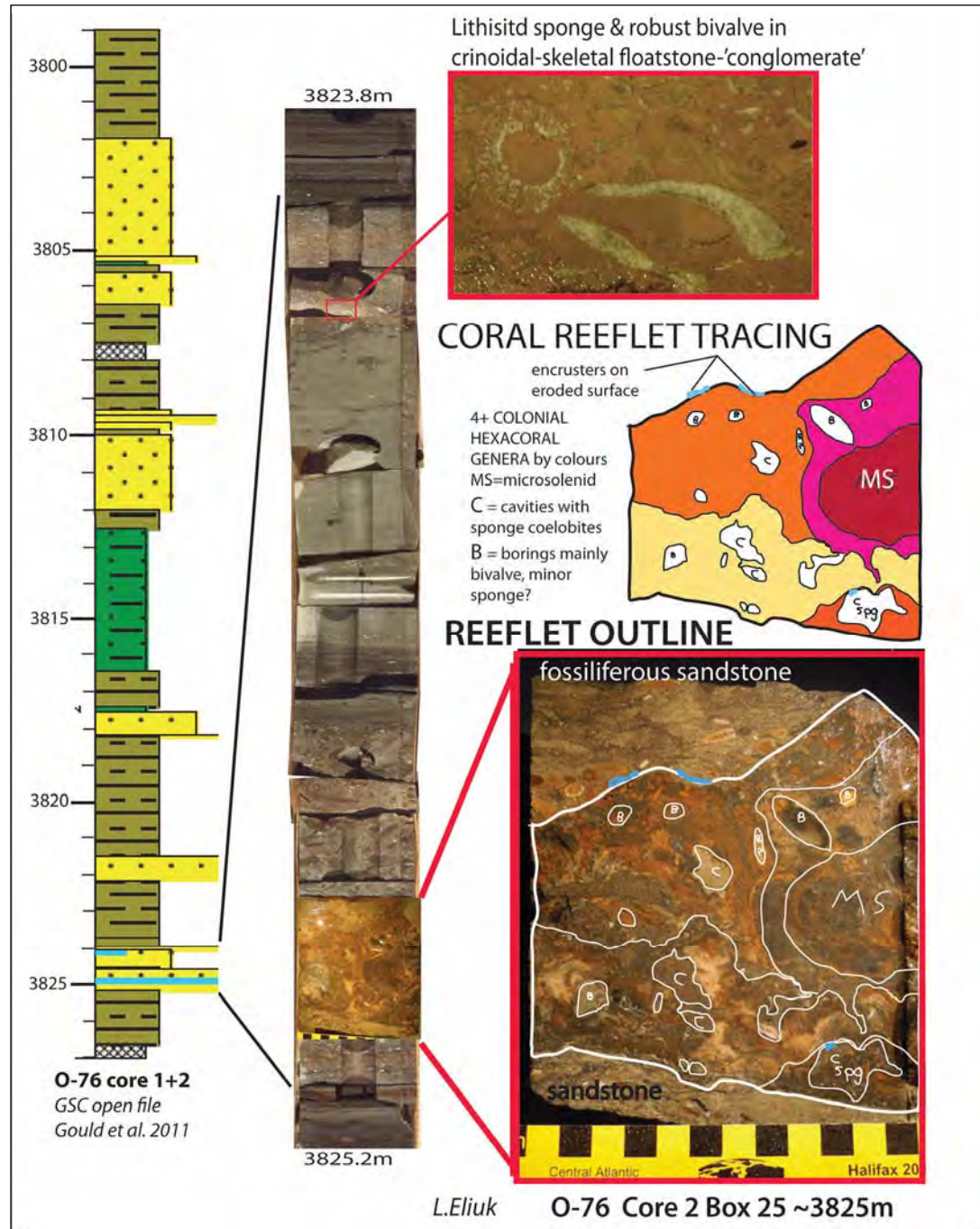


Figure 13 South Desbarres O-76 core 1 and 2 GSC (Gould et al. 2011) litholog (based on grain size graphically shown with standard lithology colours) – note 5 thin conglomerate beds with 15cm reeflet just above basal conglomerate, then 1.4 metre interval shown in whole core photo with reeflet shown enlarged from that with tracings of frame-building corals (at least 4 genera including a microsolenid) and highly bioeroded. Thin conglomerate at top of metre core photo has fossiliferous layers with large clams and a whole lithistid sponge. These fossils occur elsewhere in core but crinoid ossicles and bivalve fragments are most common. Many conglomerate fragments appear to be rounded calcareous clasts sometimes bioeroded and encrusted and occasionally large colonial and solitary coral fragments.



A CONTINENTAL-SCALE DELTA'S EFFECT ON THE NORTH END OF A JURASSIC-CRETACEOUS GIGAPLATFORM: THE ABENAKI CARBONATE-SABLE DELTA STUDY A DECADE OR SO LATER, OFFSHORE NOVA SCOTIA – WELL CORE EXAMPLES.

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Abstract

My study was to describe and understand the strange relationship of a thick extensive carbonate platform co-existing for a long time (15 Ma) beside a continental-scale delta (**Figure 1**). After finding no analogues in the modern world oceans but some interesting examples of reefs in or near deltas, an explanation was proposed to address two questions with the results not wholly convincing for the first and more satisfactory for the second.

1. Morphology, nature and origin of a big delta/thick carbonate platform juxtaposition and lateral ramp carbonates. A bathymetric 'Gap' best explains the systems' juxtaposition with their very different styles of carbonates. This interpretation is supported by vintage seismic data and the nature of the transition shown in well sections and cores. More work can be done using newer and better seismic data sets, and by considering with modelling the effect of deltaic sediment loads on creating a lateral moat and potential compensatory distal highs. Another possible control in the modern is favourable ocean currents but not easily proved in the ancient.

2. Possible lateral effects on platform margin carbonates due to proximity of deltaic sedimentation depends on location and can be nearly non-existent within the platform, subtle on the slope and profound, long continued and variable on the top during the expansion of the delta. This explanation is supported by the presence of rare, thin quartz sandstone beds or oolite nuclei on the main platform, the increasing influence of slope onlap prodelta shales, and some lateral changes in slope carbonates. There are also wholesale reef mound community changes at top of the Abenaki succession, but without presence of coarse terrigenous clastics. Further features such as common reworked microfossils, Neptunian dykes, and condensed marine redbeds indicate that the distal sedimentary section may be more gap than record with both submarine and subaerial hiatuses even including suspect mixing zone dolomite. There seems to be a consistent diachronous relationship to prodeltaic siliciclastic, sponge-rich, and marine redbed successions.

Imperfect modern analogues. The world's longest modern coral reef tract, Australia's Great Barrier Reef, ends in the Fly River Delta of the Gulf of Guinea (Tcherepanov et al. 2008, 2010). The world's largest river, Brazil's Amazon, has a long, narrow but cryptic reef tract on the edge of its wide continental shelf (Moura et al. 2016). While not platforms, these modern examples give insight into the deltaic termination of the Phanerozoic's longest carbonate platform.

Core Workshop Notes

SEE **Eliuk 2018 Talk Extended Abstract** for summary text of PhD findings and five introductory and concluding figures. To aid clarity in referencing figures the following core-related figures that support those findings will be **numbered after these overview figures starting at Figure 6**. Briefly the preceding figure captions from the talk extended abstract are as follows: **Figure 1** Comparison of two North American continental scale deltas (Sable Island and Mississippi) with a) stratigraphic charts and b) paleogeographic map; **Figure 2** Abenaki Formation paleogeography southwest of Sable Island Delta and Deep Panuke well locations; **Figure 3** Criteria supporting isolation in the form of a physical gap to explain co-existence of the large delta and



thick platform; **Figure 4** Sketch paleogeographic maps showing key features during expansion of Sable Delta on southwest Scotian Shelf; and **Figure 5** Summary model for Abenaki platform to Sable Delta relationship over time (schematic strike sections). That extended abstract also has a Table listing details on most cores studied in the PhD work.

A series of cores, partial cores and even cuttings/sidewall cores show the changes in the Abenaki carbonates from proximal and older to distal and younger relative to the enlarging Sable Island delta during Late Jurassic-Early Cretaceous (**Figure 2**). These form a diachronous spectrum from thin carbonates within the Sable delta near Sable Island to pure platform carbonates far to the southwest on the Western Shelf. But even there near the top and above the main Abenaki (Roseway) carbonates. These lateral changes are summarized even by colour changes in the same major facies along that changing spectrum (**Figure 6**).

- **South Desbarres O-76** cores 1 & 2 show corals and bryozoan-crinoid assemblages can grow within the delta but only in thin beds of sometimes less than a fraction of a metre. (These were described and illustrated in the preceding core contribution)
- **West Venture C-62** cores 12 & 13 show the #9 Limestone marker condensed beds and a sequence break with a sea-level-fall induced shoaling succession at the base of the shelf-edge Sable Delta sands. (These were described and illustrated in the preceding core contribution)
- **Penobscot L-30** cores 1 & 2 reveal the topset dark fossil-rich oolitic and foreset slope microbial carbonates associated with prograding near-delta sedimentation and forming thick limestone-sandstone couplets likely related to delta lobe shifts. **Figures 7 to 9.**
- **Margaree F-70** shows a deepening succession in a carbonate-encased pinnacle reef and the dolomite reservoir of the Deep Panuke gas field at the platform margin with little influence of the delta. **Figures 10 to 17.**
- **Demascota G-32** core 1 shows the argillaceous sponge reefs developed at the top of the Abenaki in the distal Sable prodelta. **Figures 10 and 18 to 23.**
- **Moheida P-15** shows the condensed marine redbeds overlain by thin sponge reefal beds near the limit of the Sable delta on the Western Shelf. **Figures 24 to 26.**
- **Albatross B-13** core 1 and cuttings show the continued Abenaki carbonate sedimentation into the Cretaceous beyond the influence of the Sable delta with Neptunian dykes indicated submarine drowning at the top, and red and white microbial beds on the slope. **Figures 27 to 32.**

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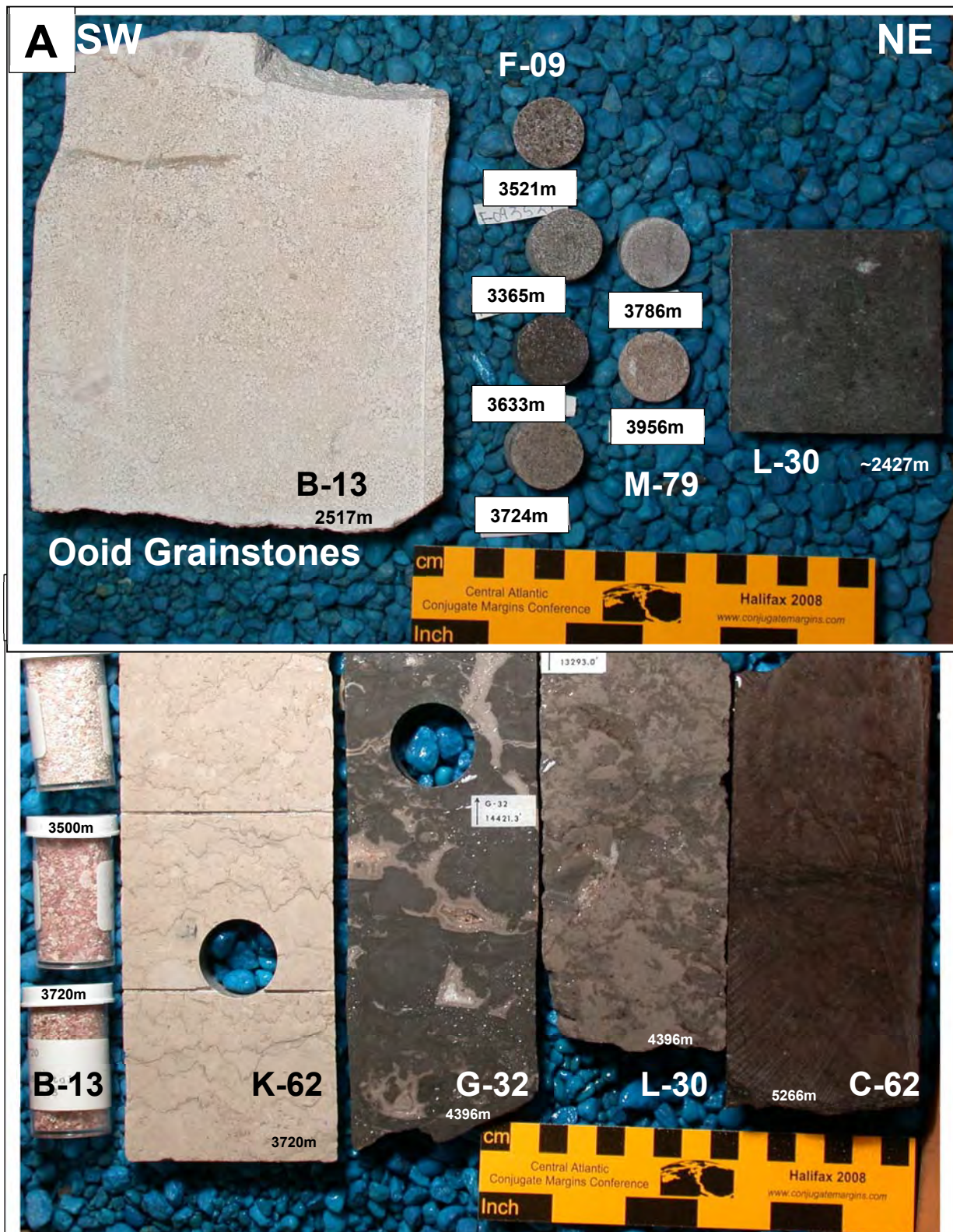


Figure 6 Southwest to northeast colour comparison of Abenaki lithofacies A) ooid grainstones and B) microbolites (thrombolites). Albatross B-13 core 1 (in A) and cuttings (in B) and Acadia K-62 core 5 of Western Shelf, Demascota G-32 core 5, Panuke F-09 and M-79 sidewall cores, Penobscot L-30 cores (1 in A, 2 in B), and West Venture C-62 core 13 of Panuke Trend to Sable Delta.



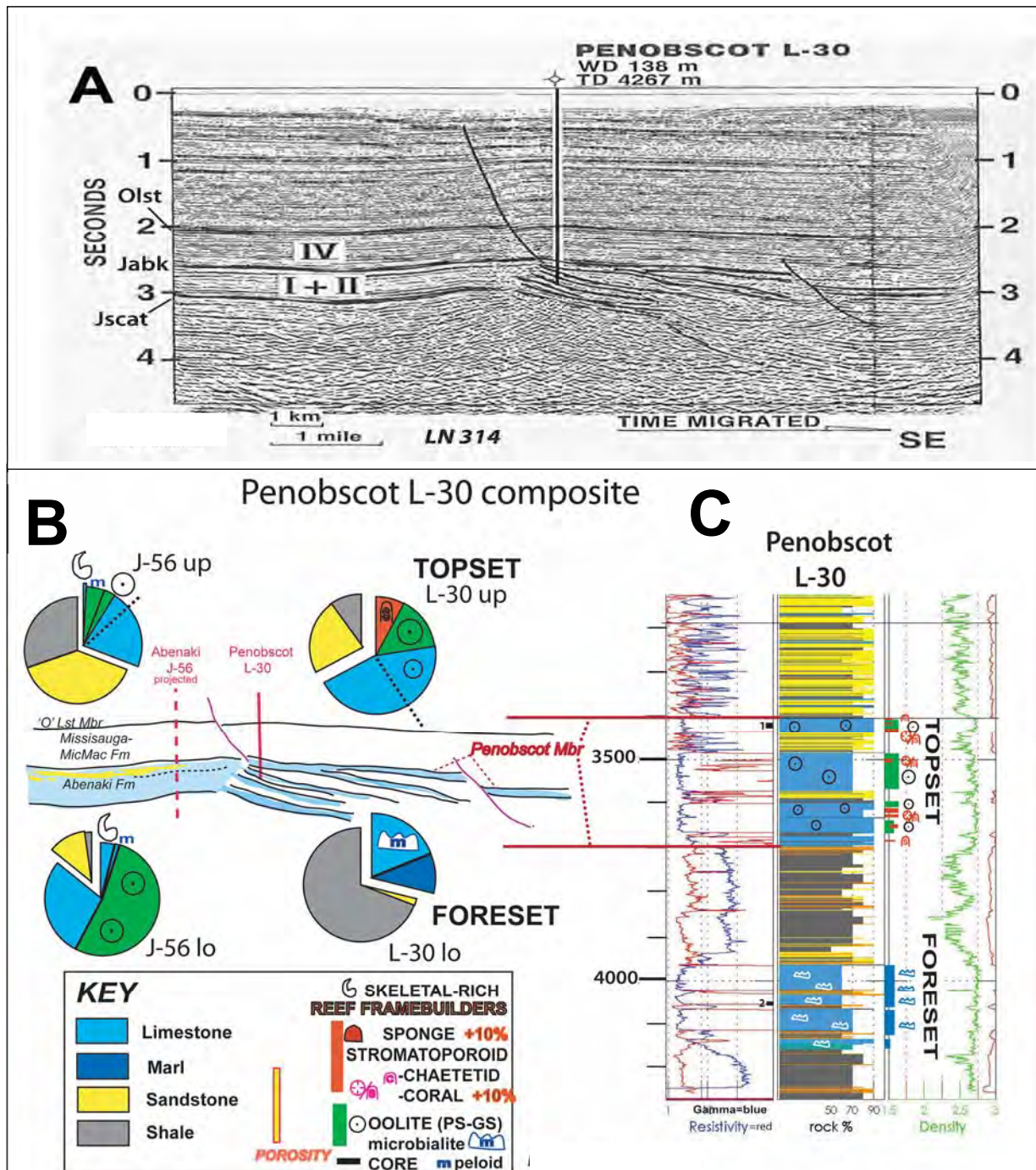
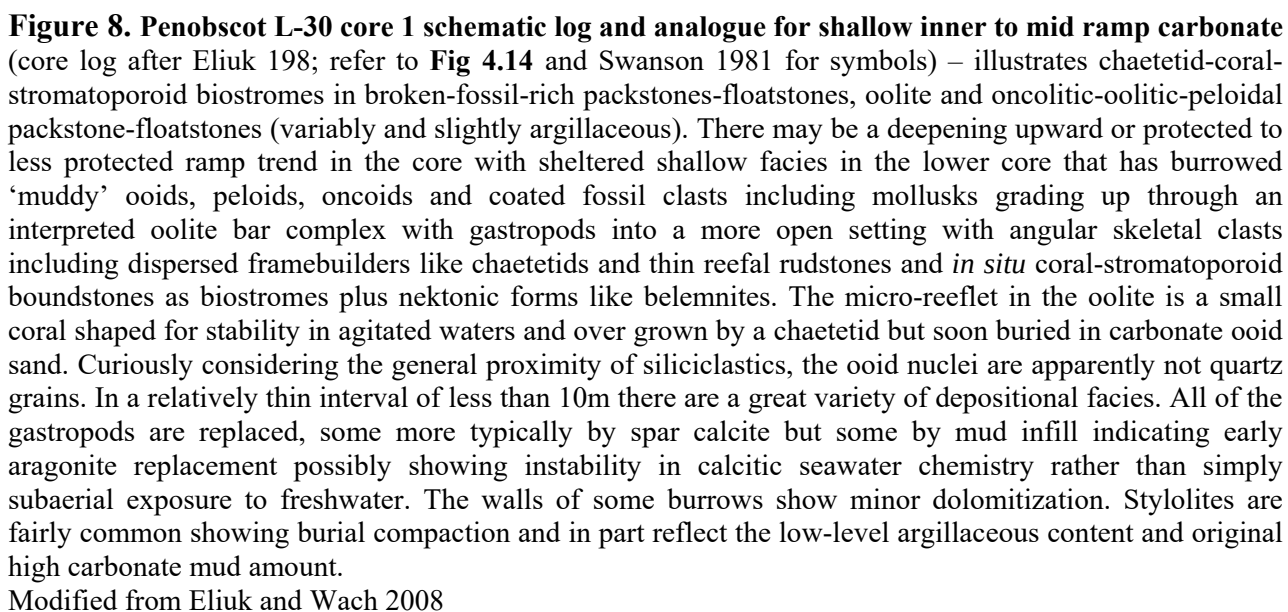


Figure 7. Penobscot L-30 area - A) dip seismic line (from Eliuk et al. 1986 similar but clearer than published seismic line in Ellis et al 1985); IV is - lower Missisauqua-MicMac formations below O Limestone and I & II Late Jurassic Abenaki Formation); **B) trace of seismic line** above with Penobscot L-30 contrasting major lithofacies in topset ramp beds and foreset slope beds basinward of upper and lower Abenaki carbonates and siliciclastics in Abenaki J-56 projected south, and **C) L-30 schematic lithology-gamma-porosity log** showing major lithofacies. Penobscot Member (Wade and MacLean 1990) dominantly oolitic with biostromal limestone on a prograding ramp basinward of the northeast end of the Abenaki Formation carbonate platform that grades upward into siliciclastics. The deeper ramp and distal platform slope are dominantly shales derived from the Sable Island Delta with deep-water microbialite (thrombolitic) limestone interbeds.

Modified Eliuk & Wach 2008, Eliuk 2016



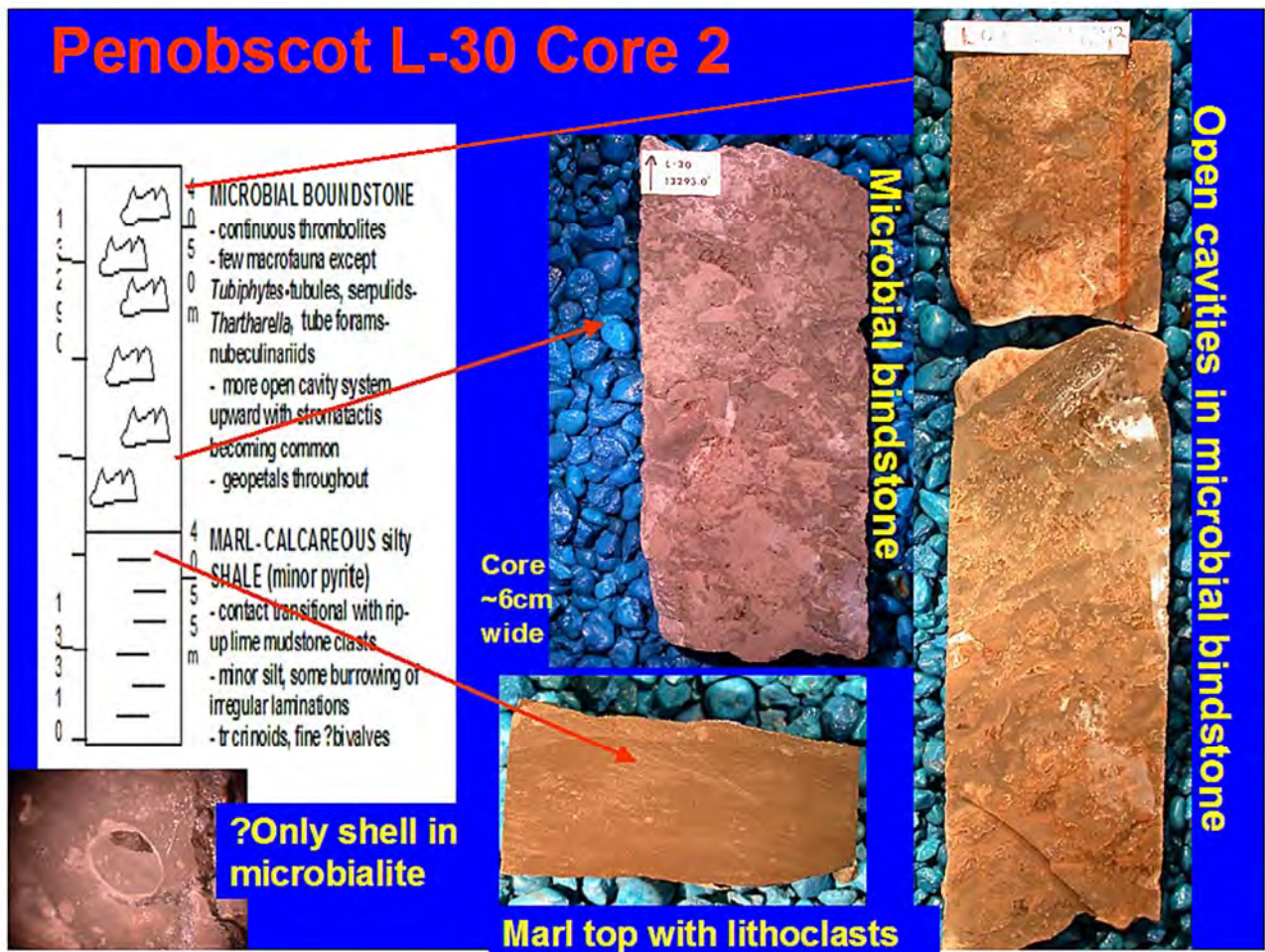


Figure 9. Penobscot L-30 core 2 schematic log and analogue for deep-water ramp and slope under siliciclastic influence – the depauperate ‘pure’ microbolite boundstone (perhaps ‘bindstone’ but not by trapping sediment as much as by very early penecontemporaneous cementation by the microbes that also likely produced peloids) with plentiful geopetal shelter fabric and minor but well distributed calcite cement in cavities that range from millimeter to centimeter and larger size in the upper part of the core. Except for a small possible lithistid sponge and small shell (?brachiopod shown) the only accessory biota is a limited variety but plentiful number of micro-encrusters – *Tubiphytes*, serpulids-terebellids-thartharellids (worm tubes) and nubecularid forams. Among the microbolites seen in the Abenaki Formation distal slope this represents an end member in terms of dark color, limited accessory micro-encrusters, uniformity of fabric and lack of different interbeds. The underlying calcareous shale to marl is also fairly uniform throughout with minor silt and some burrowing of irregular laminations and traces of crinoids and fine ?bivalves. The transition to microbolite is abrupt with small (less than a centimetre) limestone lithoclasts just below the contact. Note the inclined bedding = slope. For additional interpretation and photomicrographs on this core and Abenaki interpreted microbial sedimentation see Pratt (1982, 1985, where the Penobscot UWI was often mislabelled) and Jansa, Pratt and Dromart (1989).

modified from Eliuk and Wach 2008

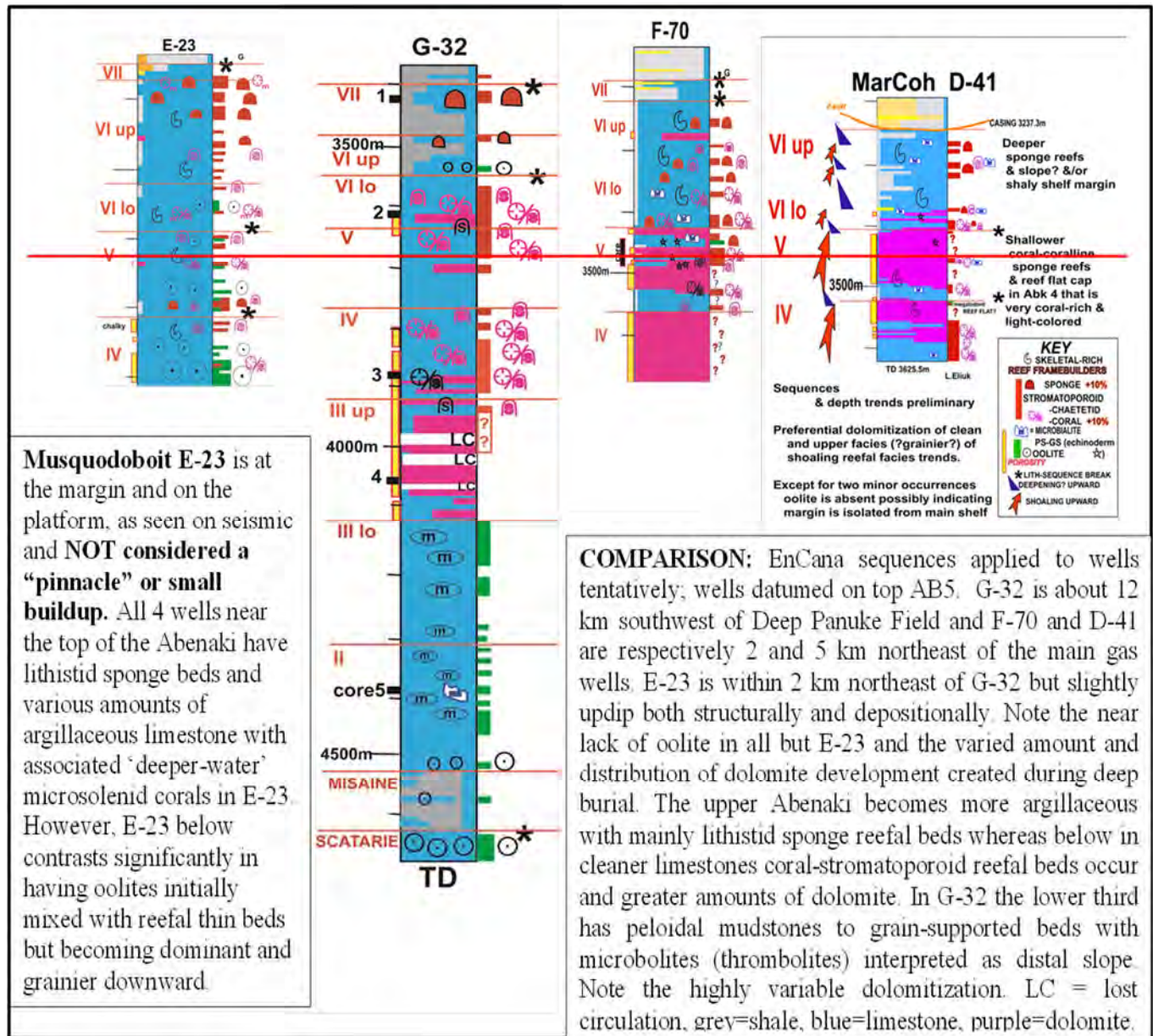


Figure 10. Comparison of interpreted "pinnacle" reef wells – Demascota G-32, Margaree F-70 and MarCoh D-41 versus typical platform well – Musquodoboit E-23. modified after Eliuk 2016

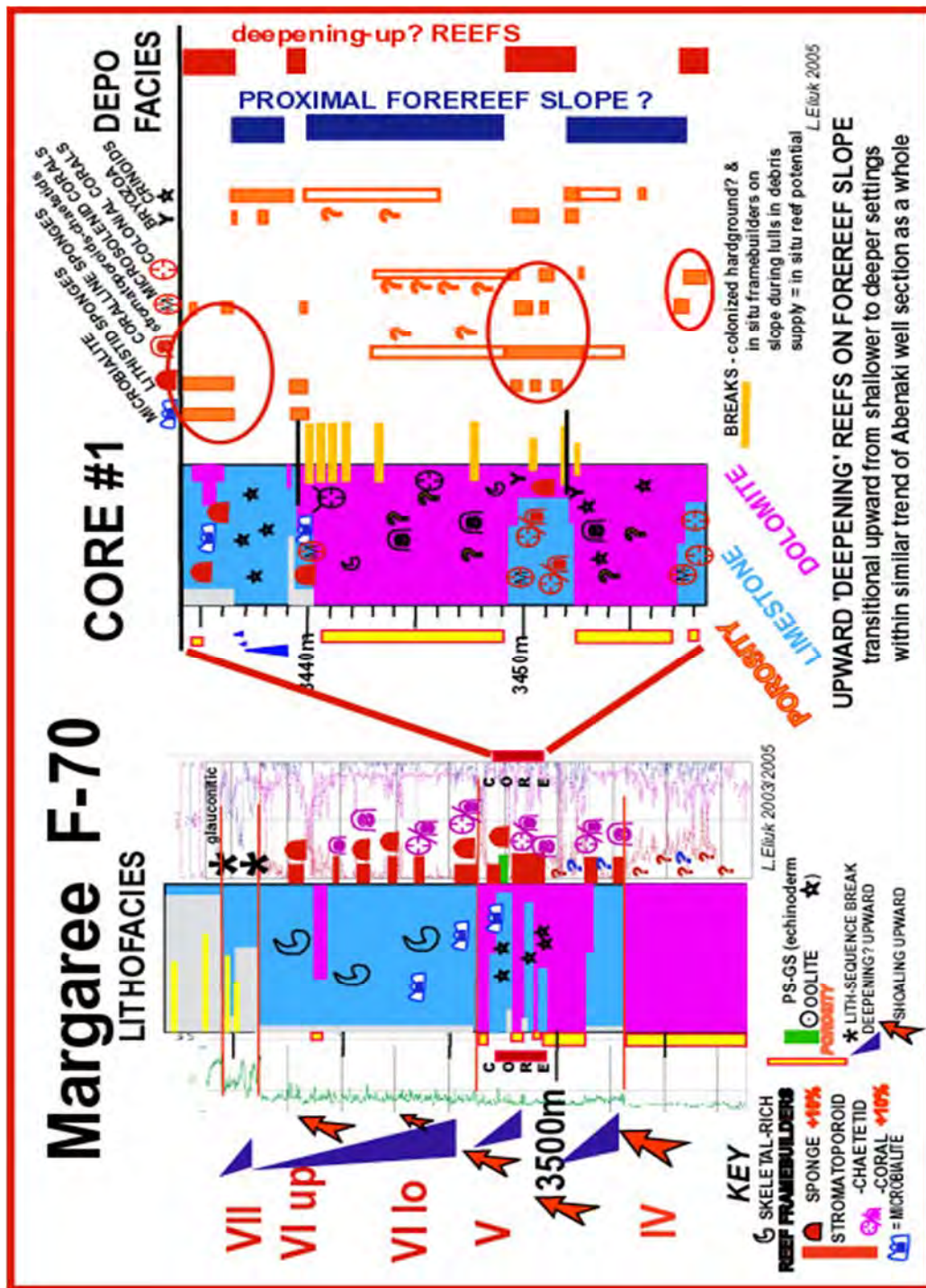


Figure 11. Margaree F-70 cuttings schematic litholog with Core #1 litholog. Sequence subdivision follows Encana sequence stratigraphy. Note upward change from coral-stromatoporoid reef beds to lithistid sponge mound beds. Core #1 is in the midst of that transition. Core litholog shows main framebuilders and interpreted depositional facies. The ovals around framebuilder groups in core interpreted as deeper-upward reef communities. The thin reefal intervals tend not to have been dolomitized as opposed to the dolomite intervals that are interpreted to have been originally grainier less submarine cemented proximal forereef slope 'sands'. See Chapter 5 (Discussion-Interpretation) for more details and illustrations of this core. (from Eliuk 2008)

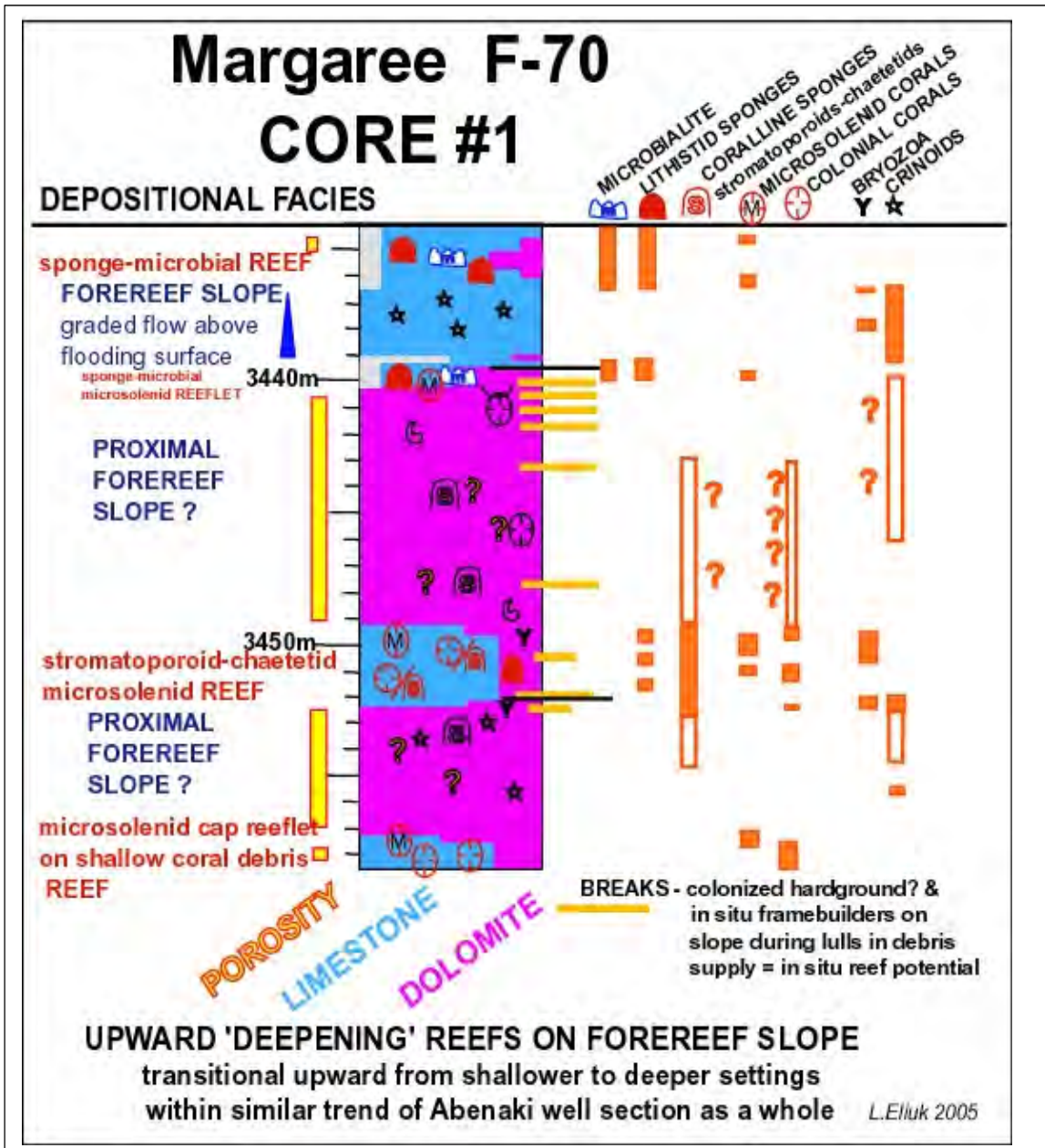


Figure 12. Margaree F-70 schematic Core #1 litholog. This more detailed interpretation of core shown on half of Fig. 10 shows the upward change from coral-stromatoporoid reef beds to lithistid sponge reef mound beds. interpreted pauses in foreslope carbonate grain supply when the surfaces were briefly colonized or thin reeflets grew. The reefal intervals change in framebuilder composition core interpreted as deeper-upward reef communities. The thin reefal intervals tend not to have been dolomitized as opposed to the dolomite intervals that are interpreted to have been originally grainier less submarine cemented proximal forereef slope 'sands'. The numbers in triangles on the far right label the 4 reefal intervals that are discussed in the text and illustrated in the following figures 12 to 18. See the Appendix A3 for detailed cuttings and core logs. A large reef clam (megalodont or dicerid) occurs at 3442.5m indicating another likely pause in sedimentation and in situ growth (added by LSE 2018-07)



Figure 13. Margaree Core 1 Basal coral reefal slabs, dolomitic limestone, large stromatoporoid-bulbous coral rudstone in a skeletal packstone matrix most *in situ* with an overturned coral colony, F-70 core 1, 3457 to 3458.7m Core width each slab ~ 8.5 cm. photos of Encana's sleeved portion of the slabbed core.

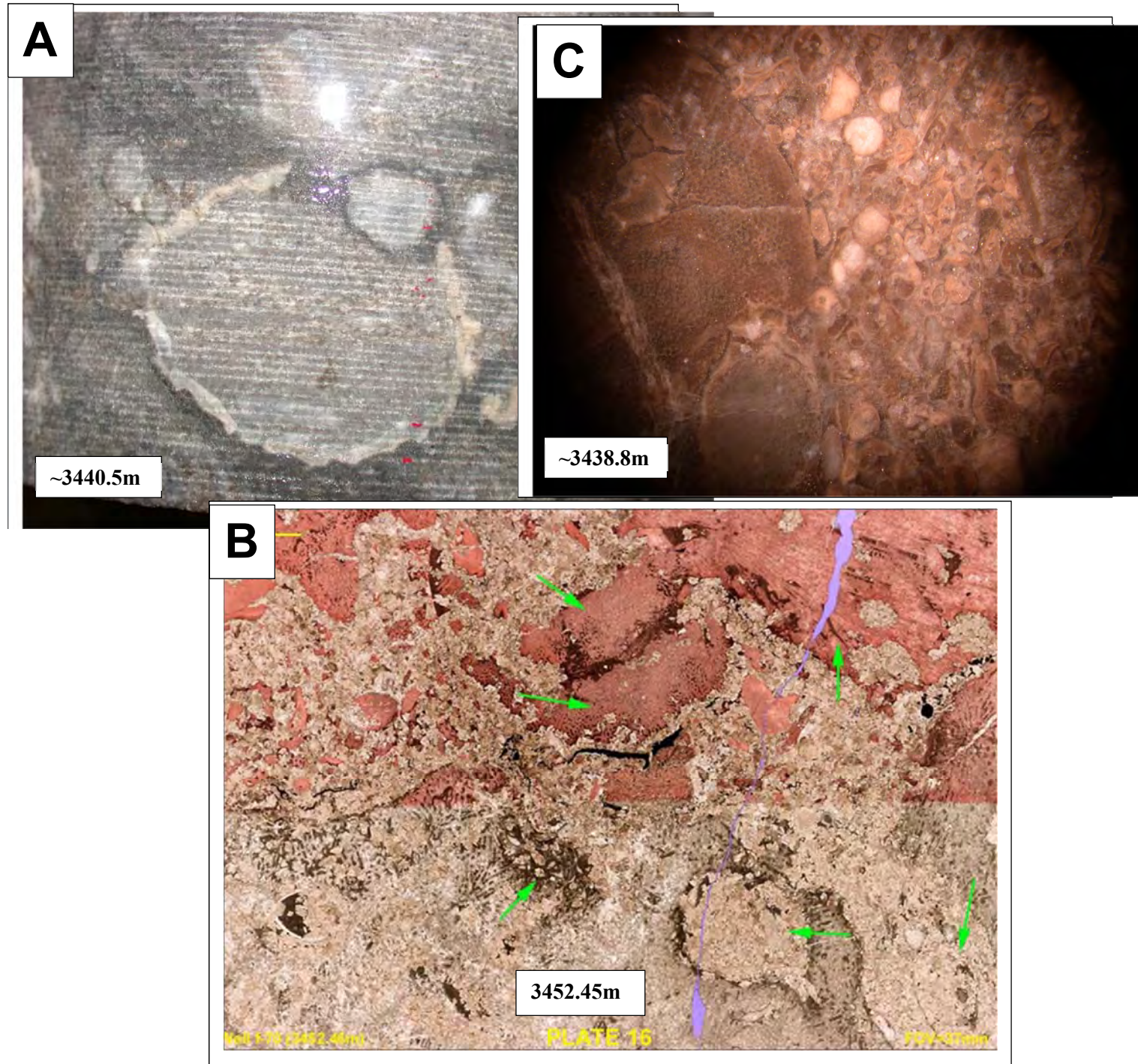


Figure 14. Margaree Core 1 photographs. A) Articulated echinoderm calyx in fabric-preserving dolomite indicating low energy period on stabilized slope during ‘break’ in sedimentation, HA= ~ 6 cm. B) Upper foreslope skeletal packstone-rudstone of coral, stromatoporoid, sponge debris with dolomite replacing matrix and partially replacing fauna, HA= 3.7 cm, alizarin red stained upper half of thin section. C) Microsolenid coral clast near base of crinoid-rich lime rudstone-grainstone debris bed, HA= ~3.5cm. HA = horizontal axis or field of view

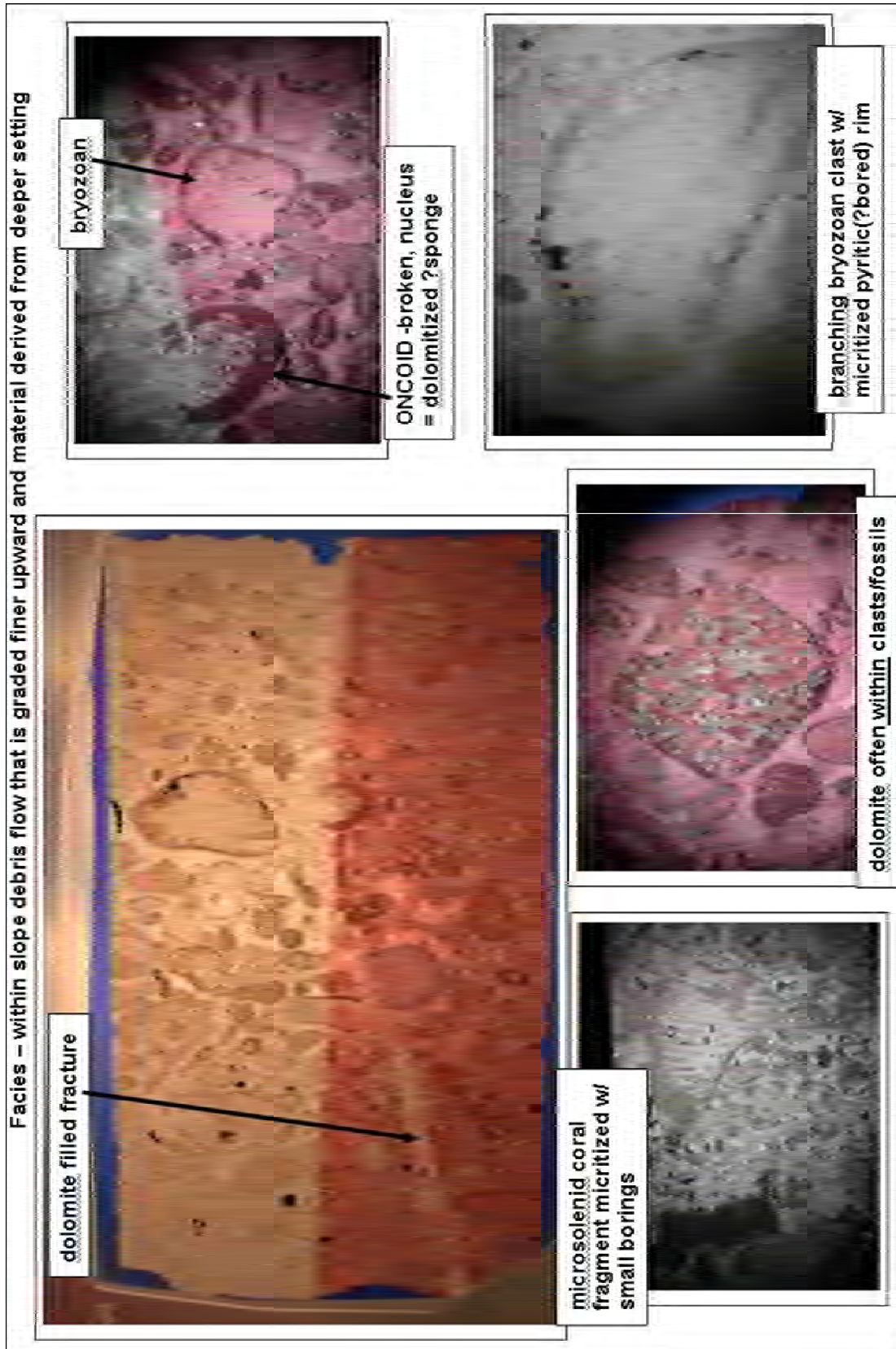


Figure 15. Margaree Core 1 photomicrographs Facies: slope debris flow, fining upward dolomitic limestone, crinoid bryozoan grainstone with scattered coarser reefal debris, F-70 core 1, 3437.5m.

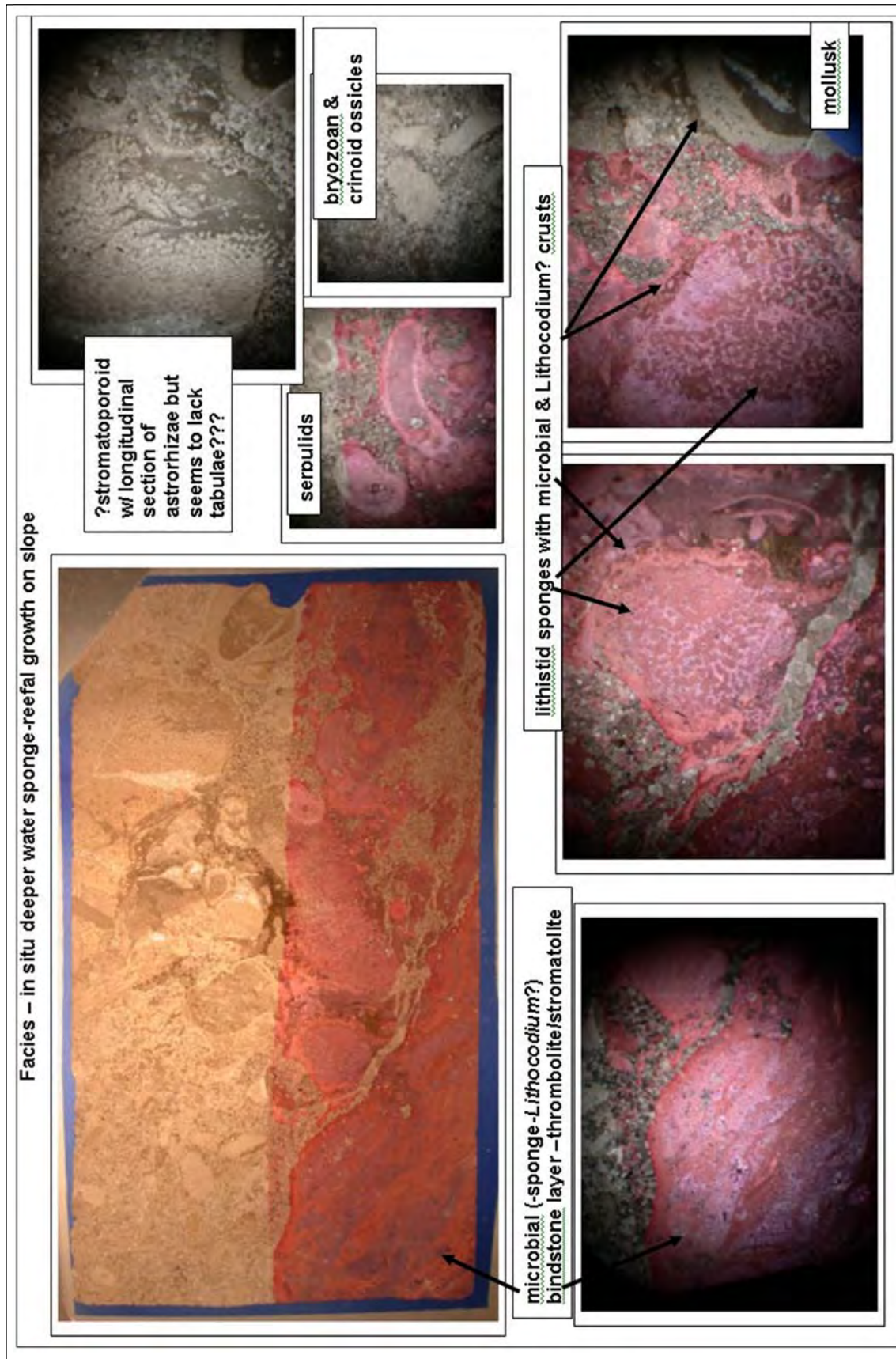
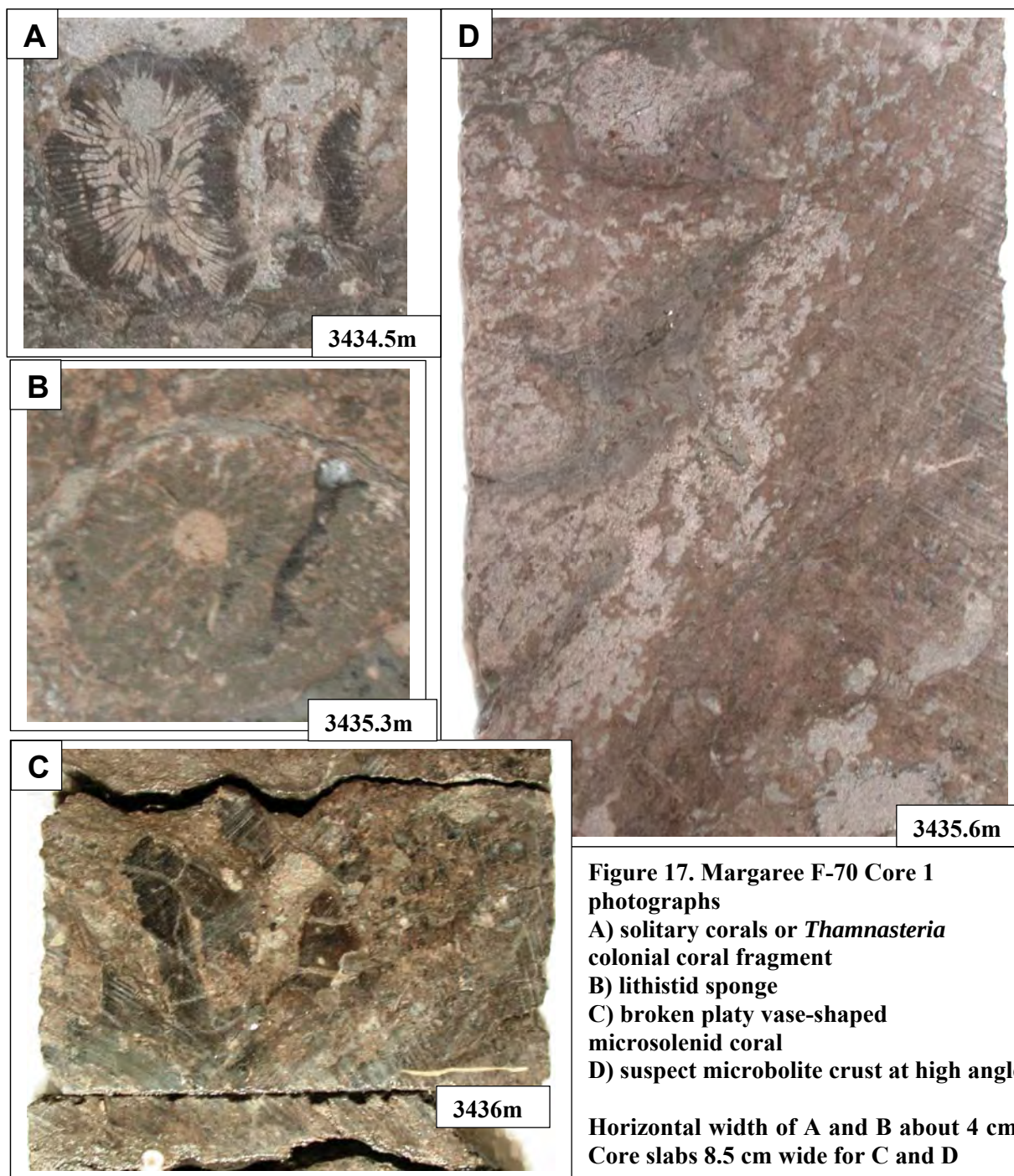
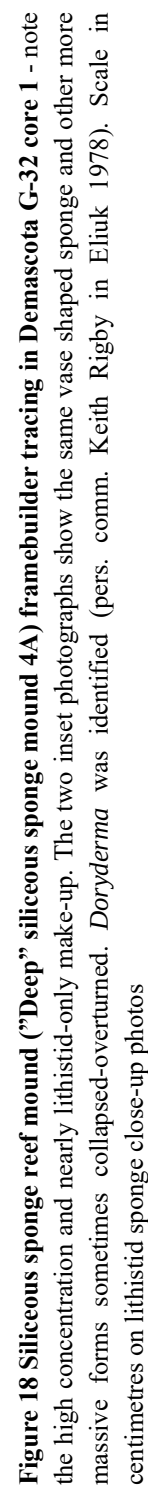
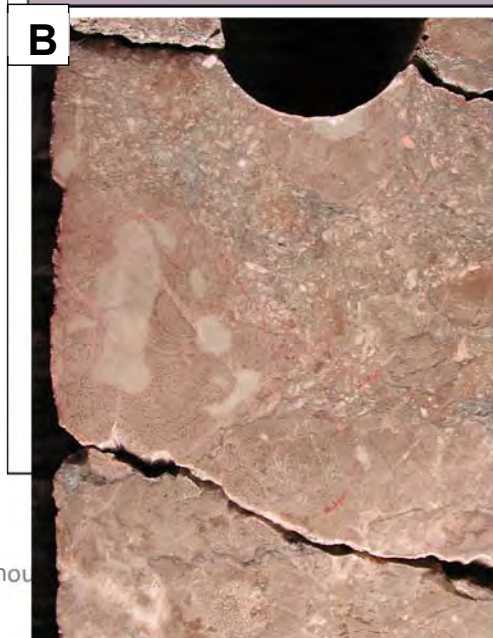


Figure 16. Margaree Core 1 photomicrographs Thin section photographs from a deeper water sponge reefal facies, F-70 core 1, 3438.6 m.







B) Lithistid sponge bound/rudstone in crinoid-tubiphytes packstone matrix. Borings? by *Entobia* (clionid sponge) in lithistid sponge. White blebs are tubiphytes. Demascota G-32: 3423.5 m = 11232'

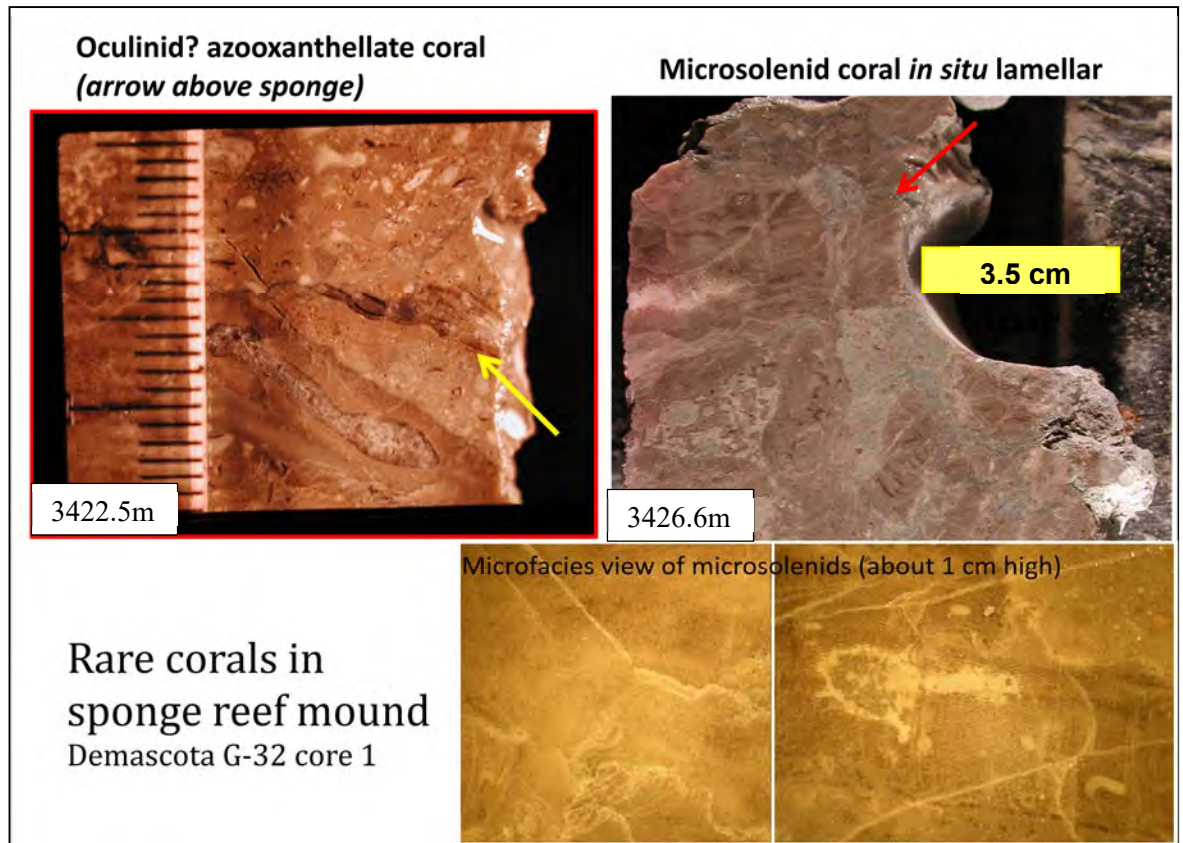


Figure 20. Sponge mound features – Corals in Demascota G-32 Core 1

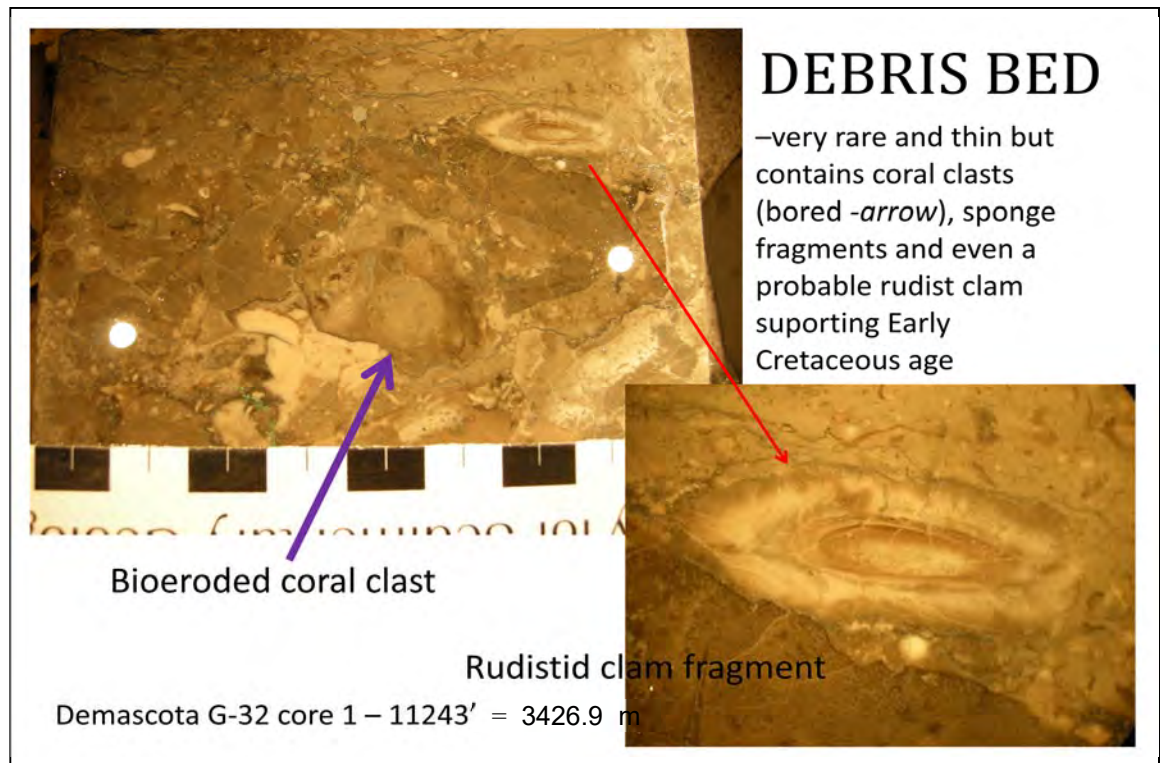


Figure 21 Sponge mound features – debris bed in Demascota G- 32 core 1 – possibly sourced from shallower shelf waters brought in by a storm (tempsestite?)

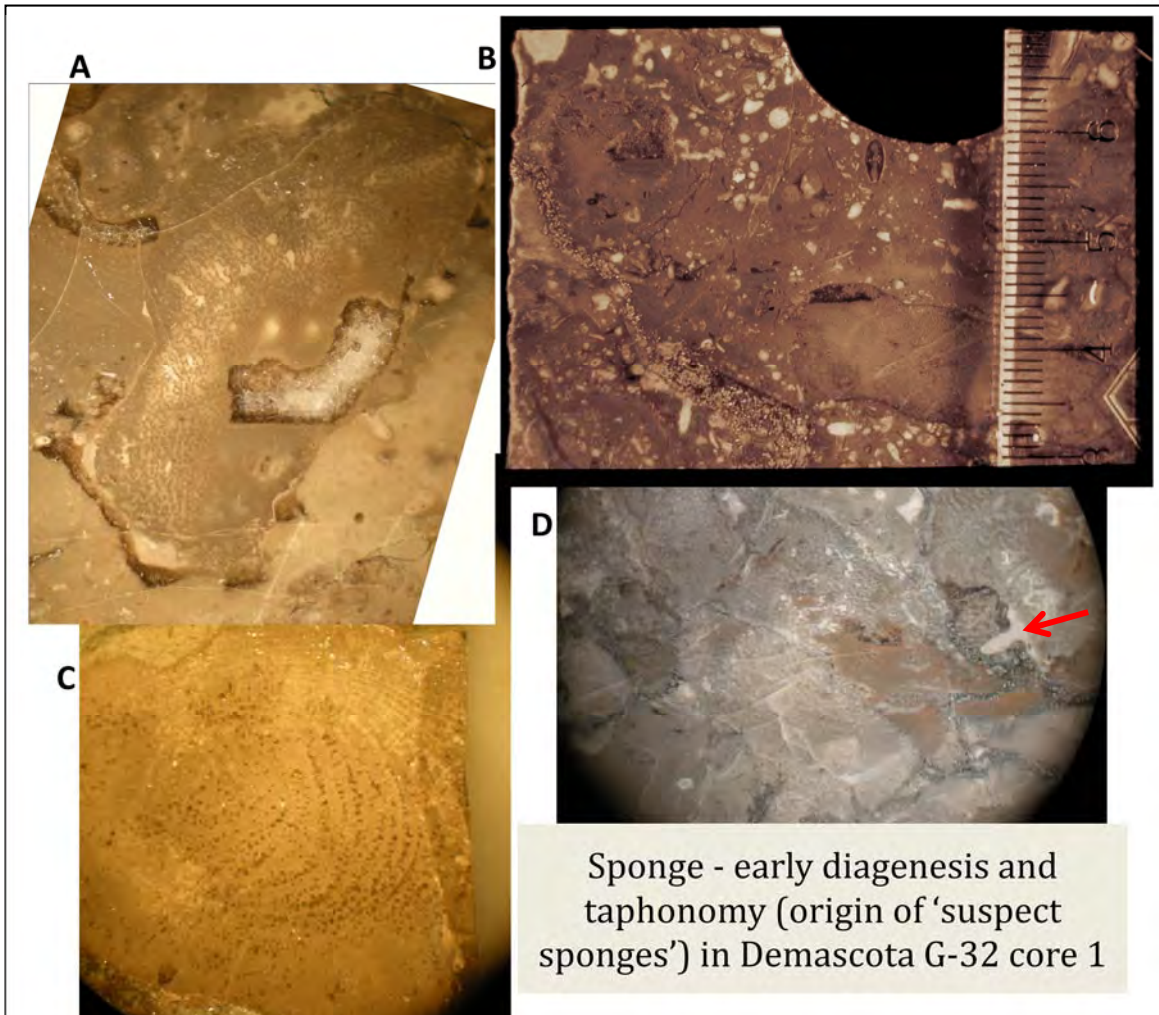
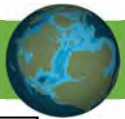
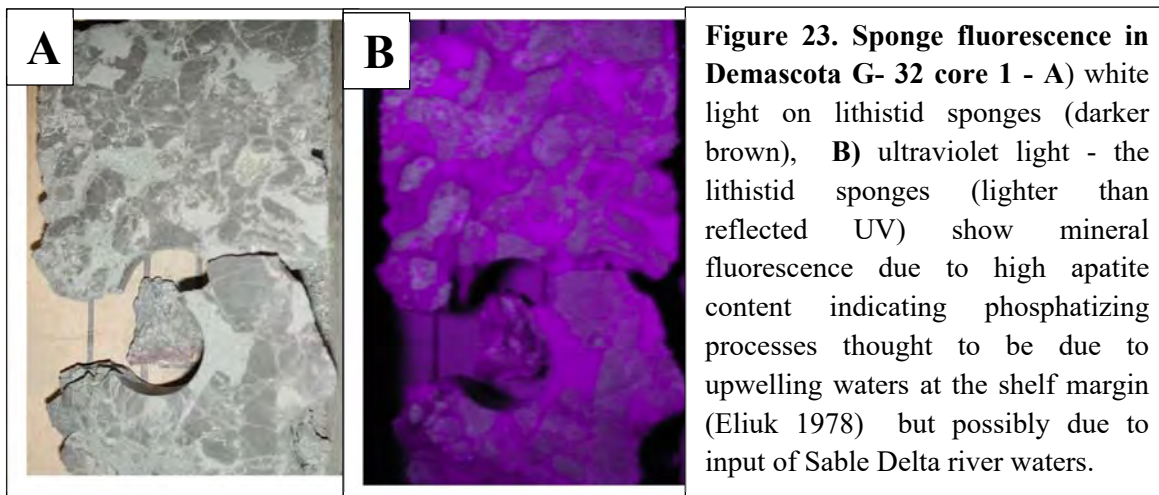


Figure 22. Sponge mound features –very early diagenesis in Demascota G- 32 core 1 – note
A) collapsing sponge material becoming internal sediment, B) similar initial collapse of sponge
C) disintegrating layers in Dactylocoelia? D) collapse of sponges on seafloor contemporaneous with sedimentation as shown by pendant tubiphytes (arrow) with reddened geopetal infill



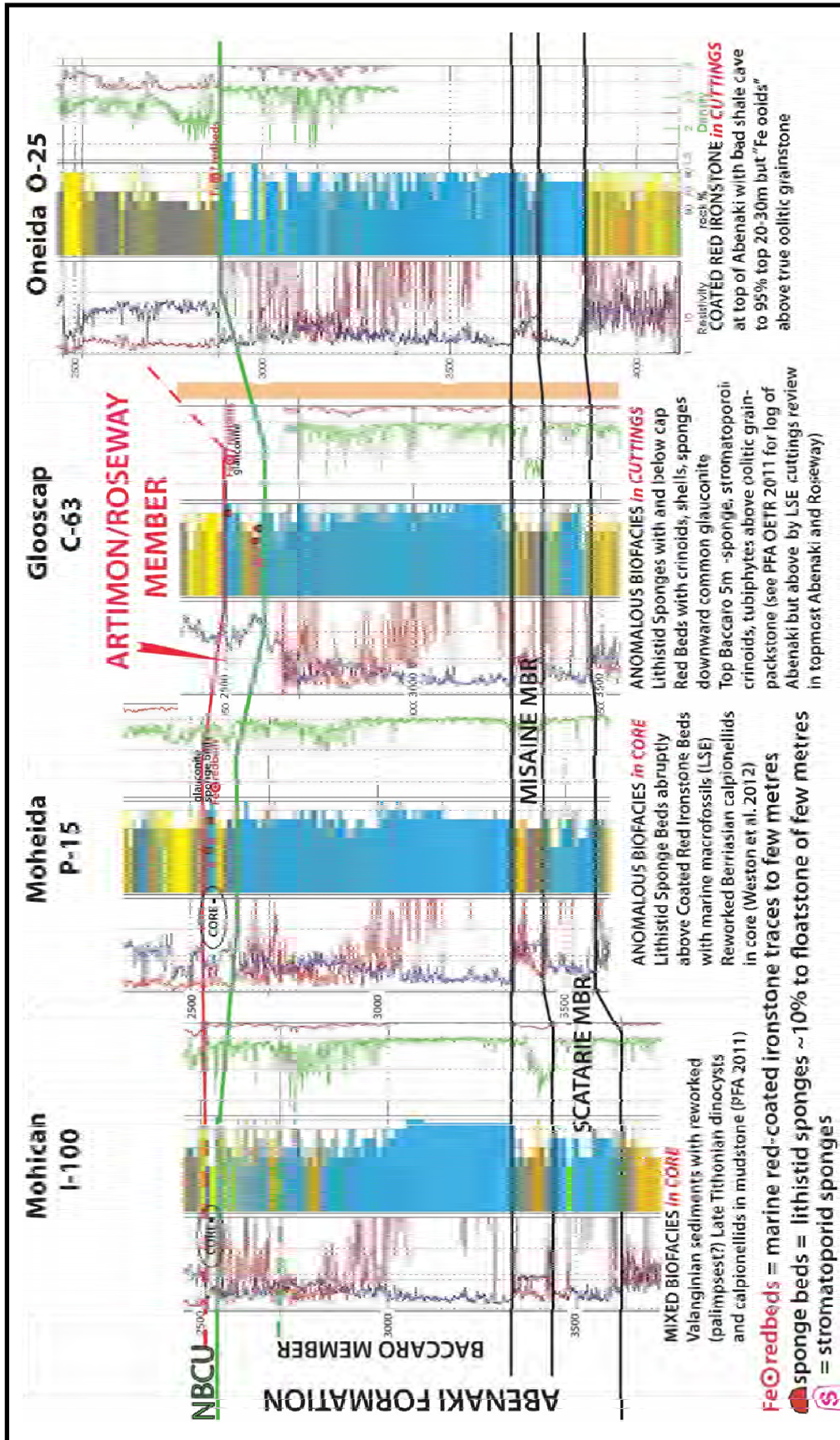


Figure 24. Red coated ironstone and sponge-bearing beds of the Mohican Subbasin on the western shelf Abenaki carbonate platform interior. The well columns are from the Appendix of the PFA report (OETR 2011) with log based lithologies and gamma, resistivity and acoustic log traces; the lithologic observations are Eliuk's. Note the greater amounts of argillaceous beds in the upper Baccaro Member. The green line marks the top of the Baccaro (Late Jurassic Abenaki member) and is about the NBCU = Near Base Cretaceous Unconformity of PFA study (OETR 2011) and Weston et al. (2012). In Glooscap C-63, Moheida P-15 and Mohican I-100 the Artimon/Roseway interval is dated as Valanginian to basal Barremian and the top-most Abenaki as Tithonian (OETR 2011, Weston et al. 2012). Problematically but not easily resolvable due to the thinness of the units, the J-150 regional top-carbonate reflector may be from above and considerably younger than its name and association with the Abenaki indicates. Eliuk 2016

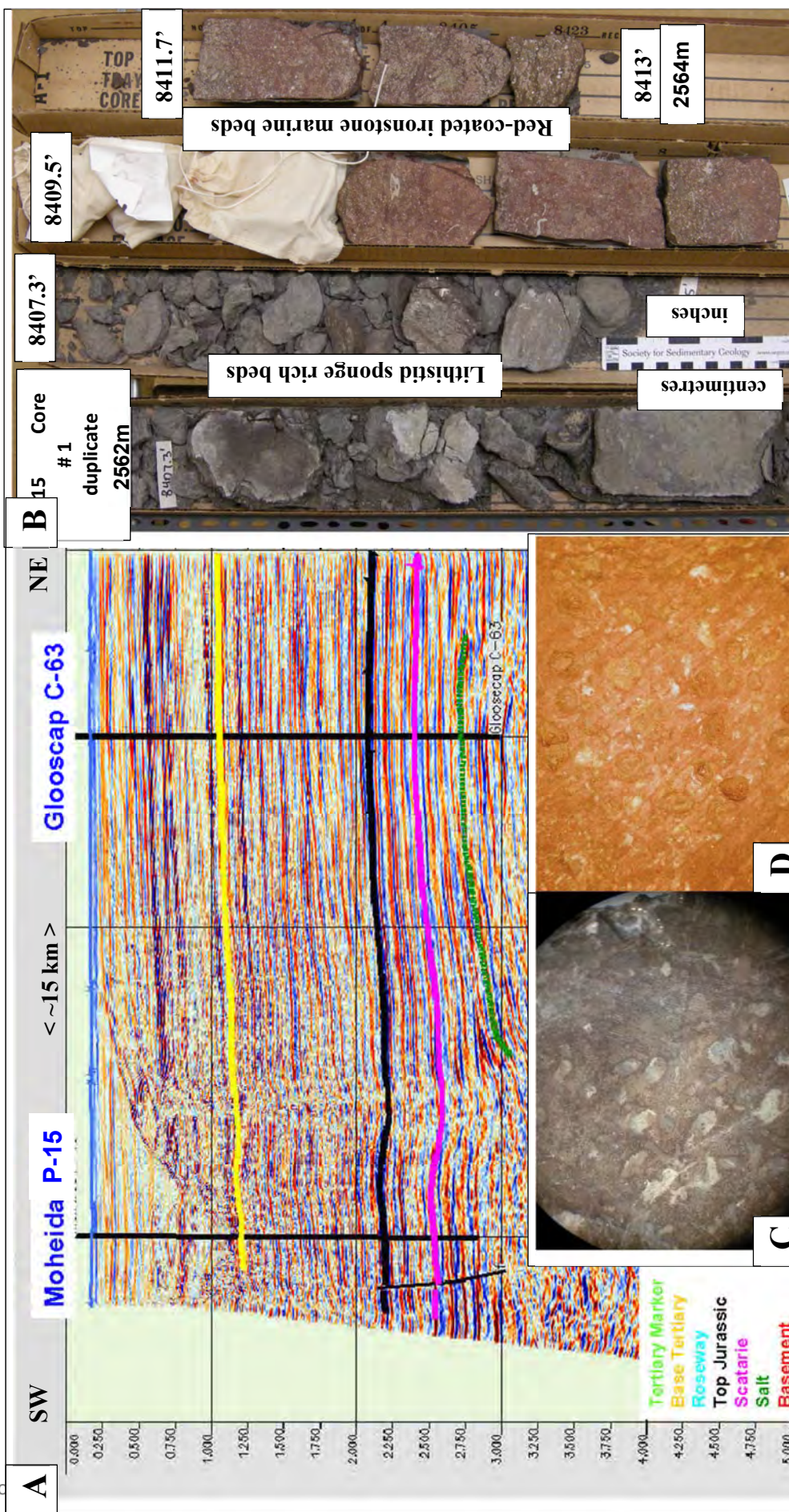


Figure 25. Moheida P-15 A) Strike Seismic line P-15 to C-63 Note downlap of reflectors onto Abenaki (Top Jurassic) towards SW with thin beds sourced from northeast Sabie Delta area. **B) P-15 Core #1** – thin argillaceous glauconitic sponge-rich limestone beds abruptly overlying thin marine redbeds of coated ironstones (“Fe ooids”). Depths as originally drilled, **C) Sponge** from upper core (view 2cm across) **D) Red coated ironstone ‘Fe-ooids’** from lower core (view 2cm across). See below for more petrography on red coated ironstones. Seismic from Kidston et al. (2005).

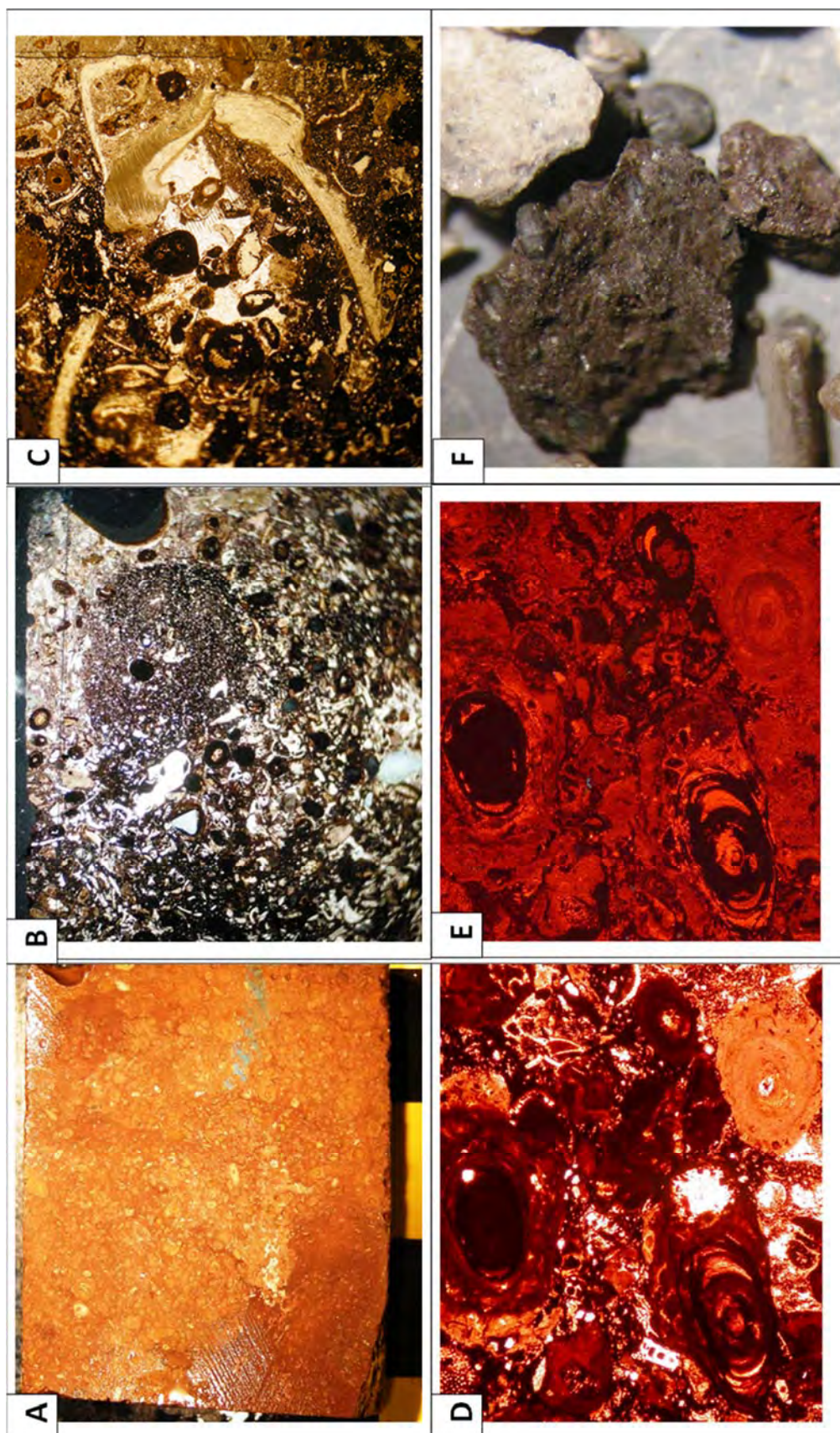


Figure 26. Red coated ironstones in core thin section and cuttings. A-E) Moheida P-15 core #1 – 8410'≈2563.4m A) Thin section sample of coated ironstone packstone with burrows upper right and lower left (cm scale at bottom), B) thin section of upper right burrow and "Fe-ooids" (1.5cm VA), C) thin section broken brachiopod-bivalve shells with minor serpulid encrustation, ostracod and echinoderm fragments and coated-ironstone grains and minor very fine quartz grains (1 cm VA), D) thin section coated-ironstone ooids-pisoids, some encrusting forams on lower left 'oid' (0.5cm VA), E) same view but cross-nicols under cathodoluminescence F) **Oneida O-25 cuttings** 9520'≈2901.7m (GSC Calgary 10 foot dry sample) rare red coated ironstone grain-packstone amongst shale cavings top Roseway/Baccaro carbonate (about 0.7cm VA). VA= vertical axis or height of photo.

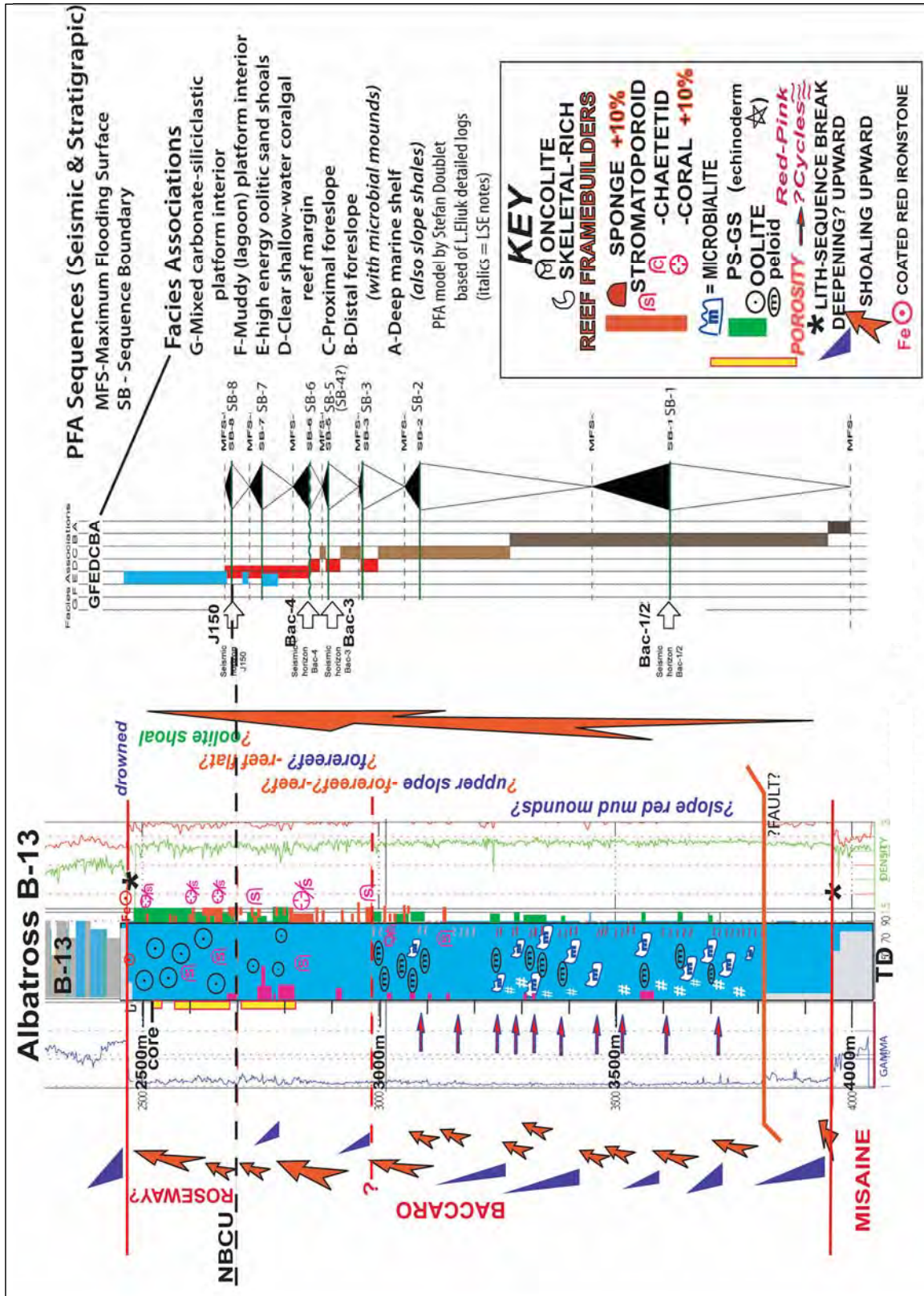


Figure 27. Albatross B-13 well schematic log with PFA sequences (OETR 2011) with key for sequences (Seismic on left e.g. J150 and depositional on right e.g. SB-8) and facies associations (bar columns e.g. G-A). NBCU= Near Base Cretaceous Unconformity.

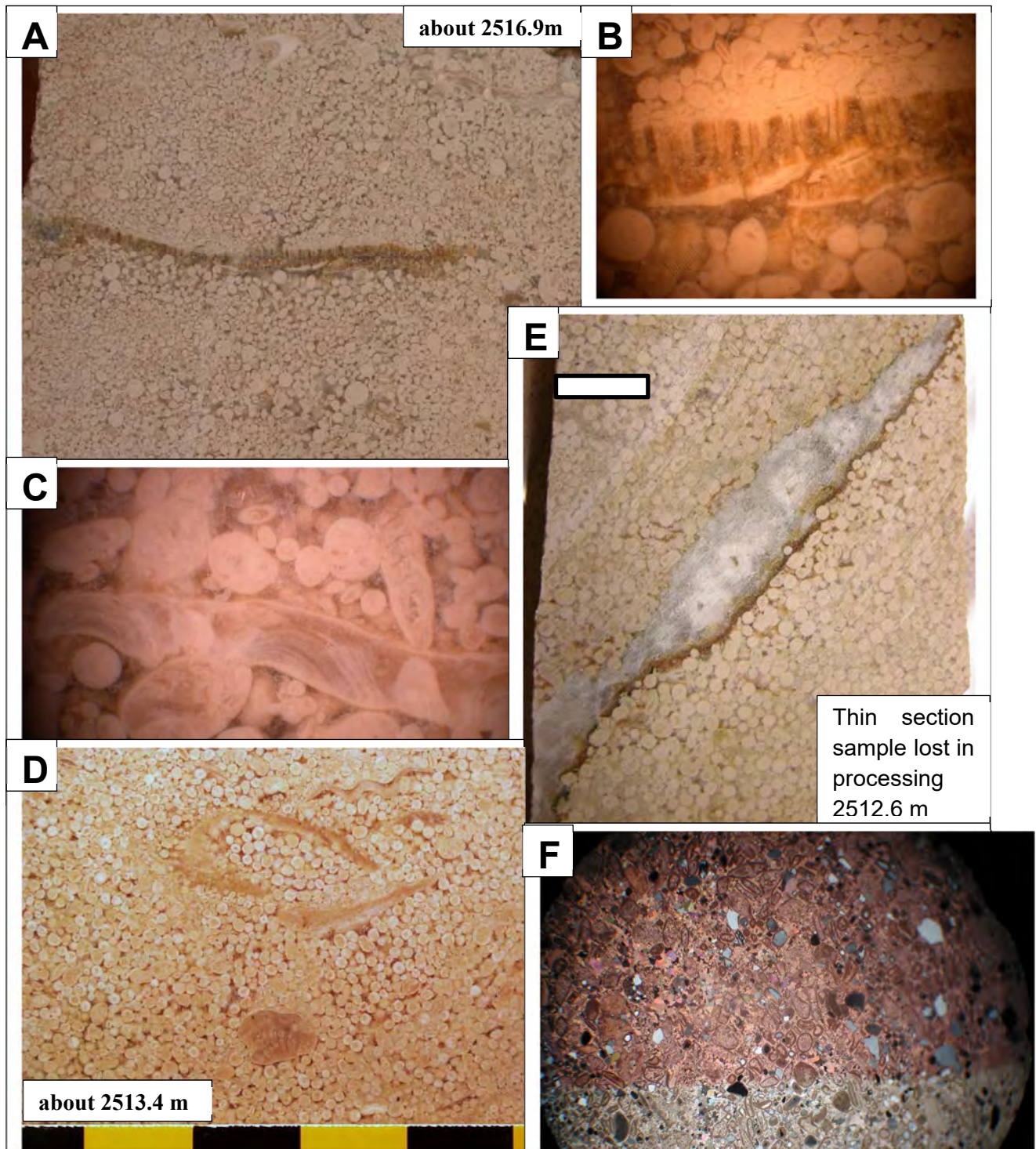


Figure 28. Albatross B-13 core 1 oolite features A-E (F-Panuke M-79 oolite with quartz).

A) Platy coral with only a single layer of corallites short-lived but ‘floating’ in ooids analogous to *Fungia* life style. **B)** Close-up of coral showing compaction breakage and sheltering from fines infill that collect on top surface. General lack of fines infilling cavity may indicate coral ‘buried alive.’ **C)** Abraided oyster fragment and small high-spired gastropod. **D)** Bivalve shells current-aligned, partly dissolved/recrystallized, rounded coral fragment in middle bottom. **E)** Fractured oolitic M-C grainstone with reddened geopetal sediment and possible red cements that also occur sporadically between ooids above the fracture. **F)** Panuke M-79 3613 m SWC alizarin stained M-C oolitic grainstone with quartz (white). Non-destructive microscopy of surface only, except thin section in M-79 sidewall core. Bars = 1 cm.

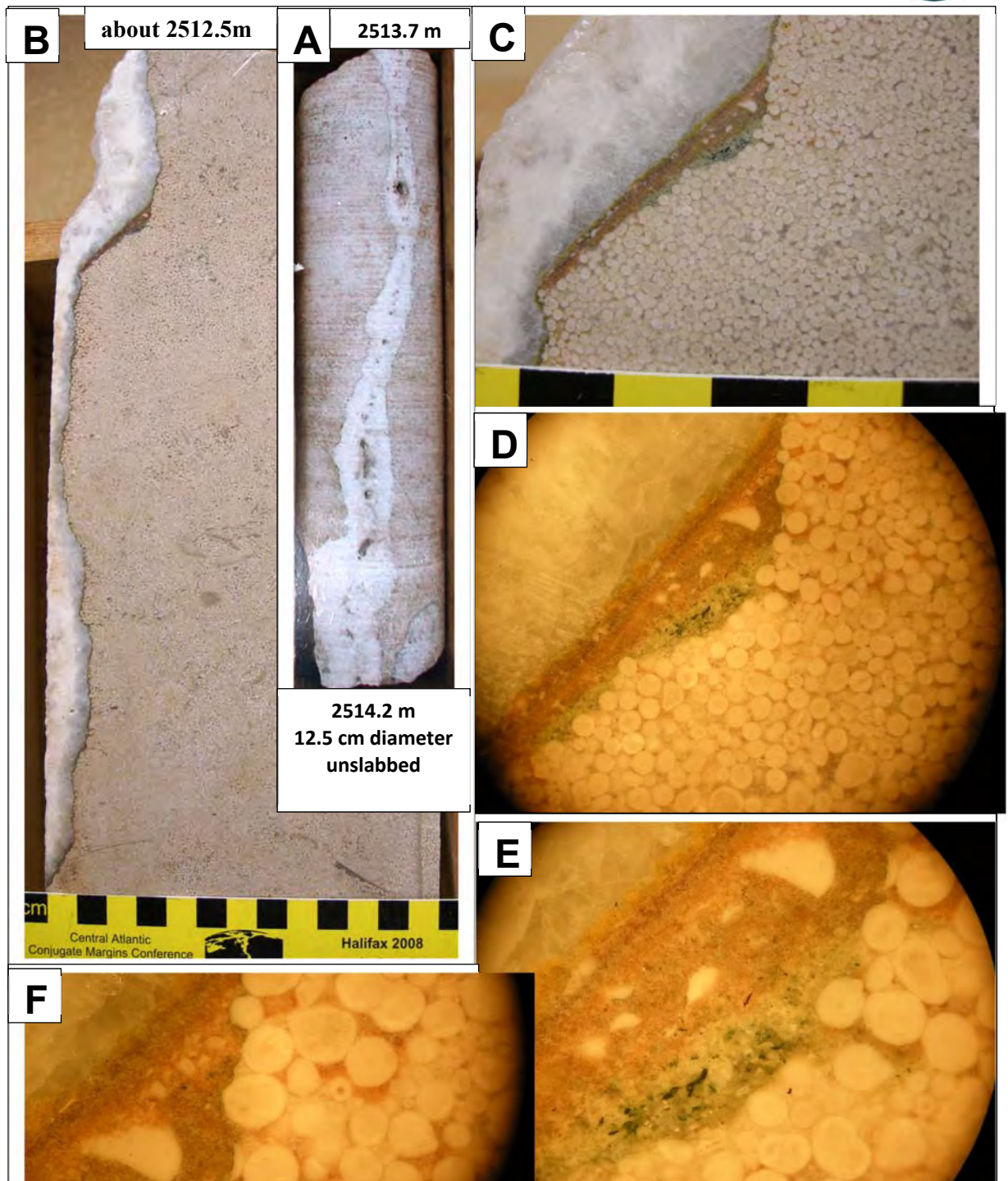


Figure 29. Albatross B-13 core 1 fractured oolite features. A) A half metre of unslabbed whole core with vertical fracture mostly cemented (ruler is in cm). B) Core slab view of oolitic lime grainstone with near vertical fractures note hanging geopetal on ledge (avalanche ‘angle of repose’?) beneath XC calcsp. C) Closer view of geopetal ledge note lower green and clear sediment/cement overlain by red layered sediment. D) Microscopic surface view of layered F debris with M-VC broken ooid fragments above country rock of a well-cemented well-sorted M-C oolitic limestone. E) Closer view showing scattered green and clear grains below red geopetal sediment. F) Yet closer view of red sediment note that some infiltrates between the ooids indicate porosity was much better during early fracture fill.

Non-destructive microscopy of surface only; CNSOPB did not allow sampling. A similar sample (Fig.28E) was taken but destroyed in thin section preparation. Third try is left to the future.

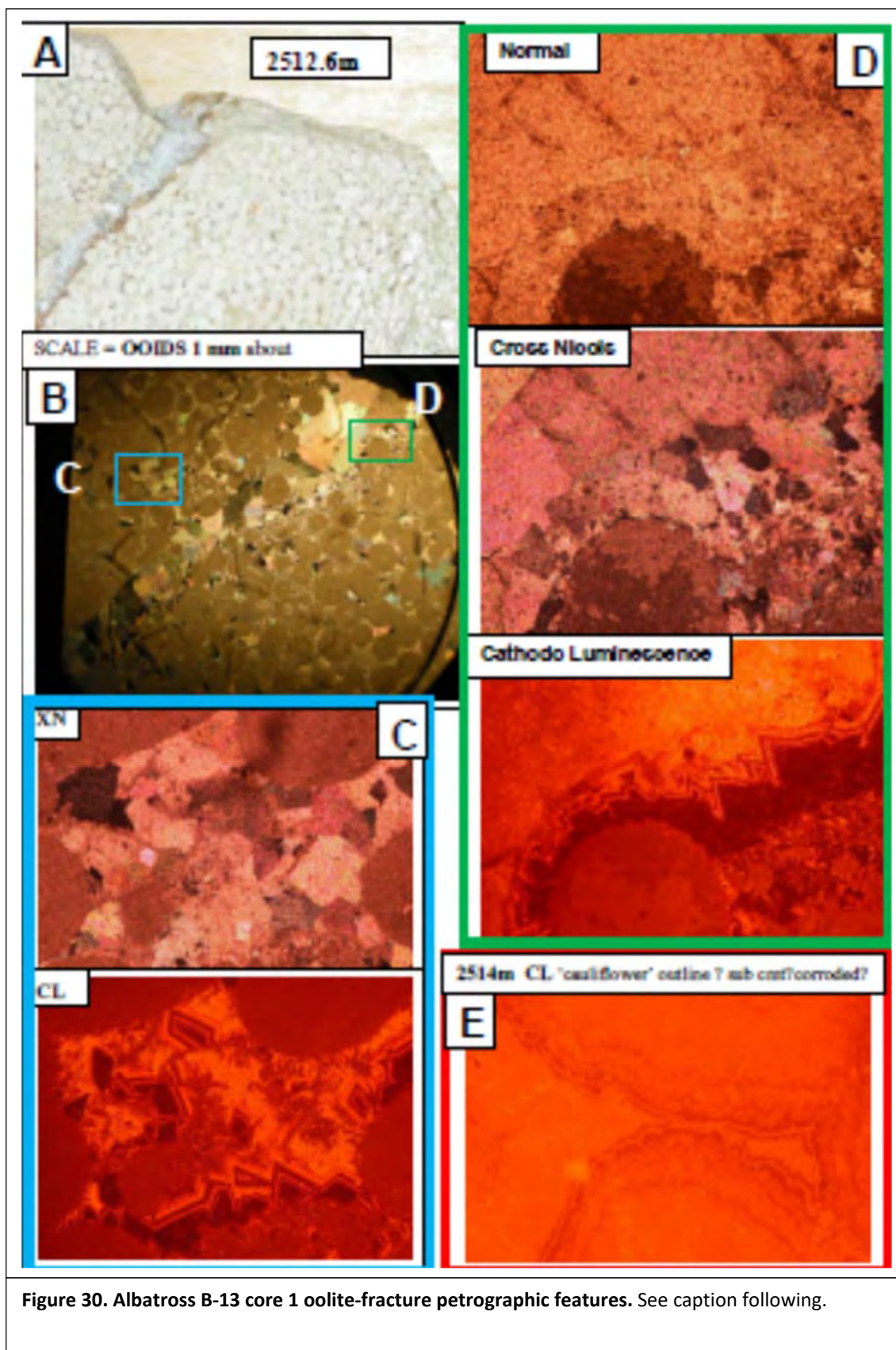




Figure 30. Albatross B-13 core 1 oolite-fracture petrographic features.

A) Thin section sample at 2512.6 m showing macro-view of oblique cemented fractures in white M-C oolite lime grainstone. Note the thin red sediment-cement occurring only on the lower side of the fracturing in a geopetal manner.

B) Low power thin section crossed-nicol view of sampled fracture. The blue rectangle by the white C is the area of view of the higher power view of the sample in Figure 4.78C and similarly the green rectangle by D in Figure 4.78D. Horizontal view about 1.5 cm and larger ooids about 1 mm (coarse) for scale.

C) Crossed nicol and cathodoluminescence views of inter-ooid cements. Note the earliest cement is dark and interpreted as quenched due to iron content followed by thinner zoned cements. The general pattern seems the same as the cements along the fracture shown in Figure 4.75D giving a cement stratigraphy.

D) Normal, cross nicol and cathodoluminescence of the lower edge of the fracture. Again the first cement is dark and covers both the recrystallized ooids and a layer of very fine sediment. That the cement post-dates the sediment infill is consonant with the observation in Figure 4.77D-F of some red material getting in among the ooids. However there must have been significant early cementation for the oolite to retain its form and brittle fracture.

E) Oolite thin section view of sample at 2514 m of two ooids and isopachous cement. The cementation must have been in a phreatic environment with no hint of meniscus cements. The zoning is present but thinner and fainter. The cement crystal termination seems somewhat rounded and perhaps suffered some kind of corrosion.

Horizontal area of view about 1 mm.

**B**

Albatross B-13 Abenaki cuttings

Figure 31. Albatross B-13 lower Abenaki limestone cuttings colours **A)** Cyclic repeat of (7) white up to red then (about 2-3) white up to pink in trays going from base lower left to top upper right with paper labels at top of cycles or giving depths (darker bottom 5 trays on lower left = argillaceous limestones; dark cuttings in 3 middle left trays due to lost circulation material such as mica). **B)** Representative cuttings close-ups with peloid and microbolite thrombolitic textures.

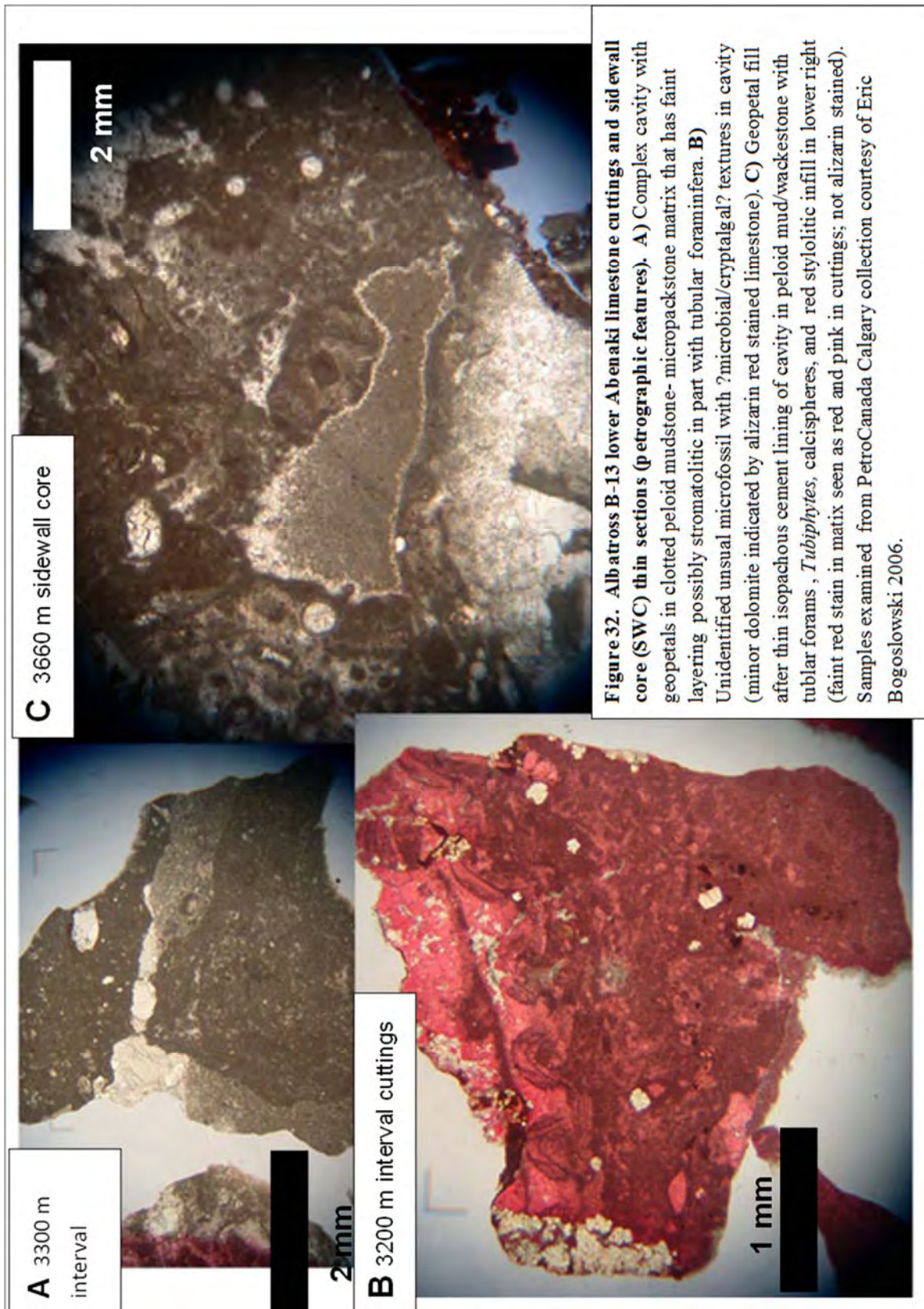


Figure 32. Albatross B-13 lower Abenaki limestone cuttings and sidewall core (SWC) thin sections (petrographic features). **A)** Complex cavity with geopetals in clotted peloid mudstone-micropackstone matrix that has faint layering possibly stromatolitic in part with tubular foraminifera. **B)** Unidentified unusual microfossil with ?microbial/cryptalgal? textures in cavity (minor dolomite indicated by alizarin red stained limestone). **C)** Geopetal fill after thin isopachous cement lining of cavity in peloid mud/wackestone with tubular forams, *Tubiphytes*, calcispheres, and red stylolitic infill in lower right (faint red stain in matrix seen as red and pink in cuttings; not alizarin stained). Samples examined from PetroCanada Calgary collection courtesy of Eric Bogoslawski 2006.





JURASSIC ENVIRONMENTS (IROQUOIS FORMATION) OF THE SCOTIAN BASIN, NOVA SCOTIA, CANADA

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Abstract

The Lower?–Middle Jurassic core 8 from the Mohican I-100 well was analyzed to gain a better understanding of Early and Middle Jurassic carbonate and evaporitic environments along the central Atlantic margin during the formation of the proto-Atlantic Ocean. The studied core is part of the Iroquois Formation (Lower?–Middle Jurassic; Weston et al., 2012), in the offshore Scotian Basin.

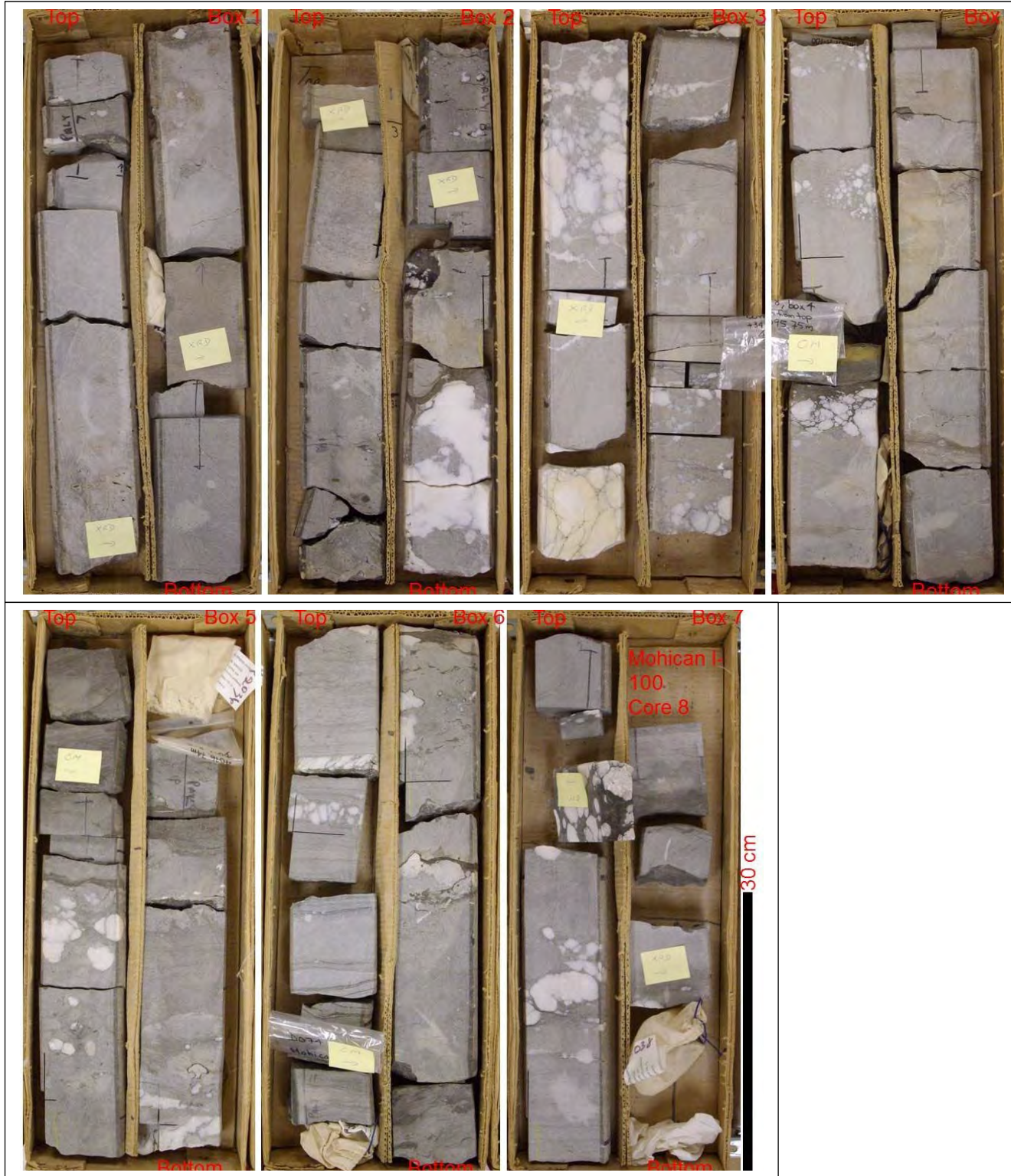
The Mohican I-100 core 8 consists mostly of dolostones and dolomitic limestones, with obstruction of micro-sedimentary features common throughout most thin sections. Core 8 is interpreted to correspond to alternating intervals of semi-arid/coastal plain/marginal marine? deposits with restricted lagoonal (marine influenced) deposits. Microbial mat/tidal flat facies alternating with anhydrite is described here for the first time for this core. Overall, base level changes lead to the transition from a restricted setting into a higher energy, less restricted environment, with semi-arid coastal plain intervals appearing infrequently.

References

Weston, J.F., MacRae, R.A., Ascoli, P., Cooper, M.K.E., Fensome, R.A., Shaw, D., and Williams, G.L., 2012. A revised biostratigraphic and well-log sequence stratigraphic framework for the Scotian Margin, offshore eastern Canada. *Canadian Journal of Earth Sciences*, **49**(12): 1417-1462.



13425'
4091.4m



13450.1' = 4099.6m

Figure 1. Mohican I-100 core 8 – slabbed whole core photographs. White = anhydrite. Grey = dolomite. Paper labels indicate thin section sample locations



Figure 2. Microbial mat



Figure 3. Sedimentary discontinuity

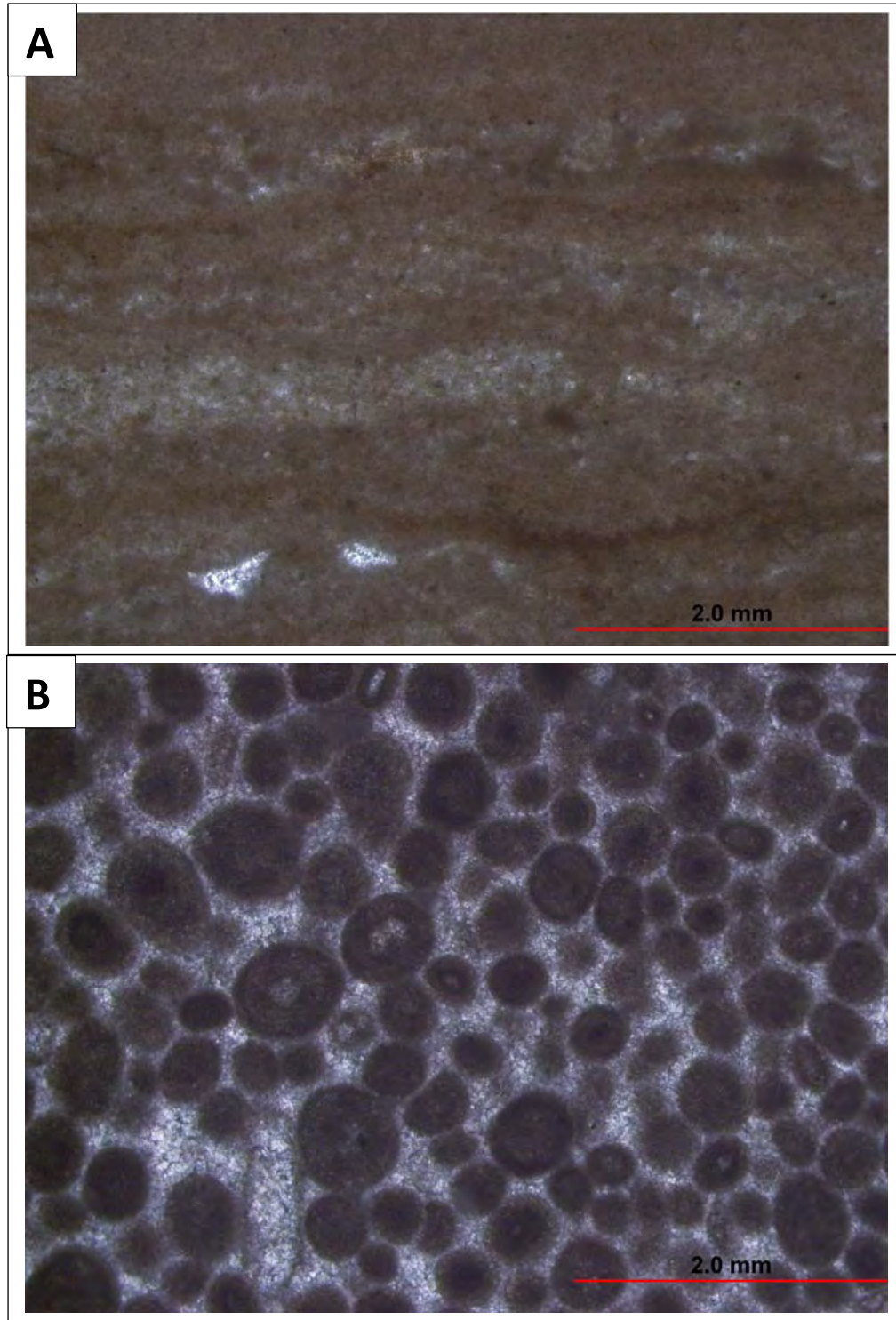


Figure 4. Dolomite photomicrographs. **A-** microbial mat. **B-** oolitic grainstone

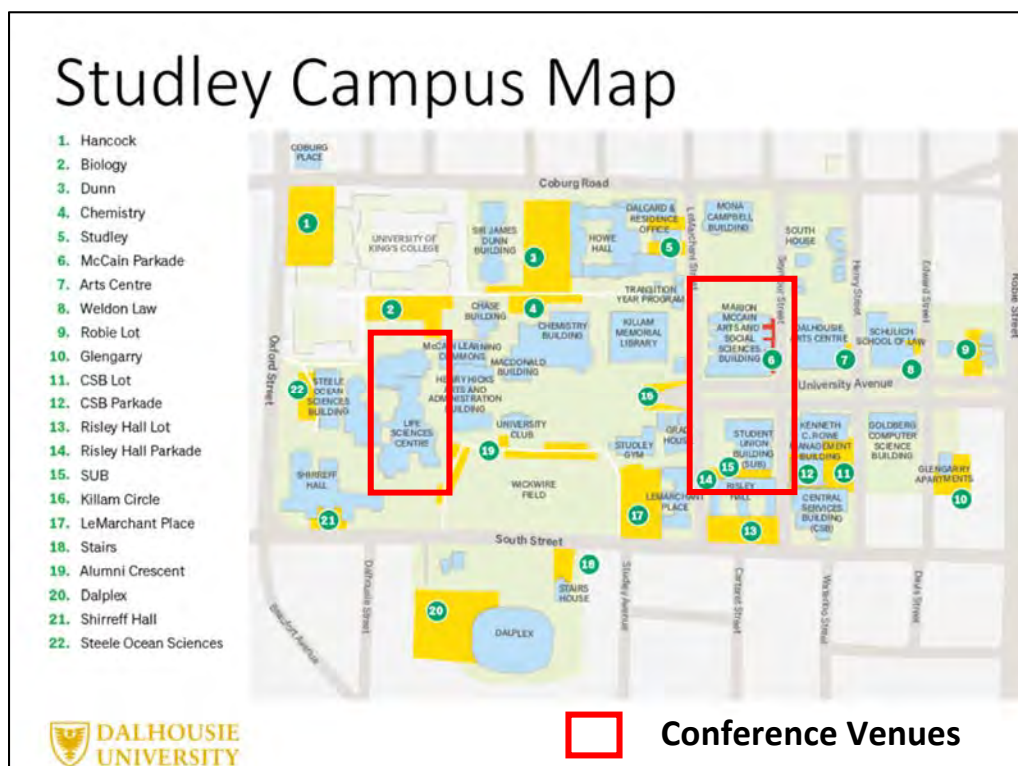


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Dalhousie University is the venue for the 6th Conjugate Margins Conference. It is one of Canada's oldest universities with 2018 marking its 200th anniversary. Dalhousie is the largest educational institute in Eastern Canada with approximately 19,000 students and degree programs in 12 undergraduate, graduate, and professional faculties. It is highly regarded for its research and related facilities, especially with respect to medicine, law, engineering, and ocean sciences. The university is located in an area of the city surrounded by parks, residential properties, and hospital facilities, and about a pleasant, 30-minute walk or short taxi drive from Halifax's downtown area.

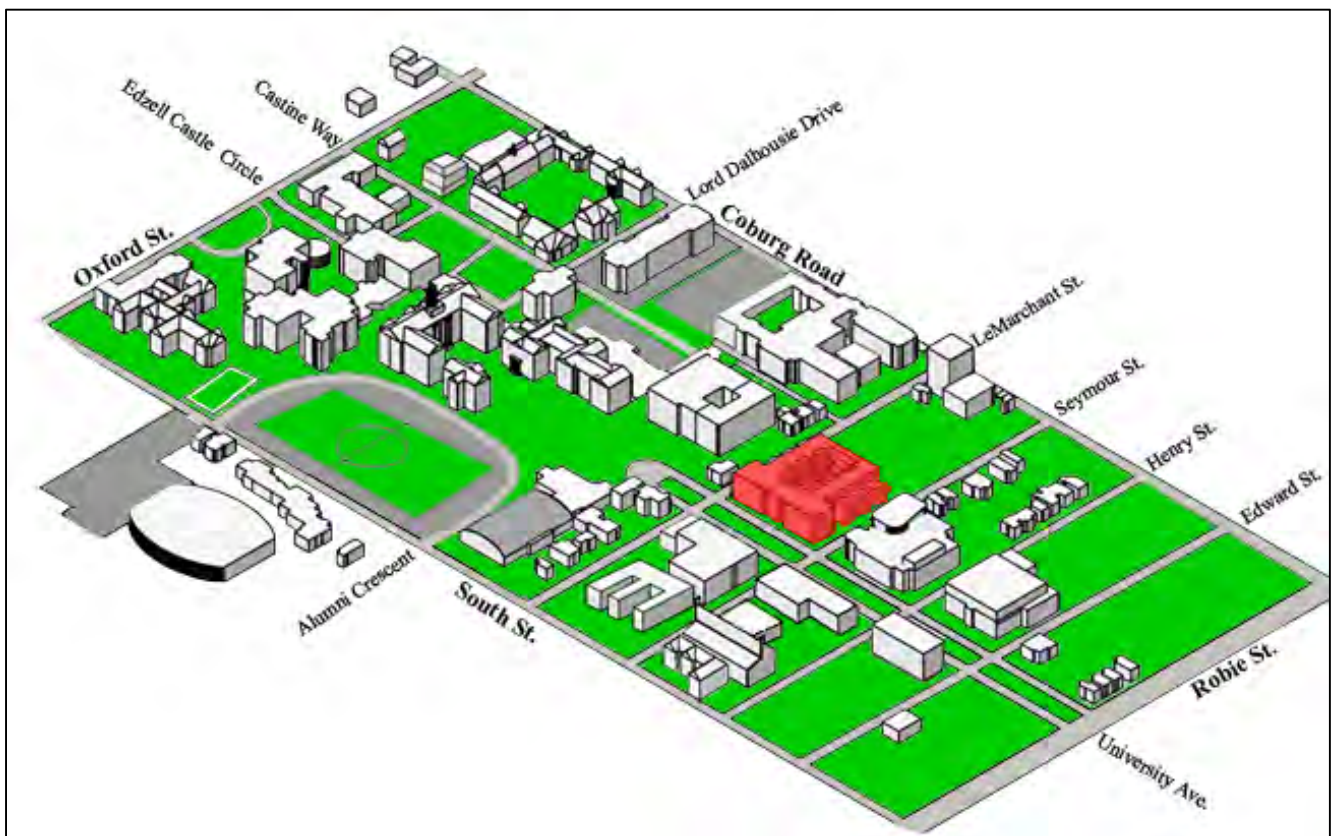




Marion McCain Arts & Social Sciences Building



The *Marion McCain Arts & Social Sciences Building* is the location of the conference's oral presentation sessions taking place Scotiabank Auditorium (left side of foyer) and Ondaatje Theatre (right side of foyer), both on the main floor.





Dalhousie University Student Union Building (SUB)



Directly across the street from the McCain Building is Dalhousie University's *Student Union Building (SUB)*. Conference registration is on the SUB main floor, with the icebreaker reception, poster session, corporate displays, G&G Data Rooms, and all lunches and refreshment breaks on the second floor. Field trips will depart and return from the front of this building.

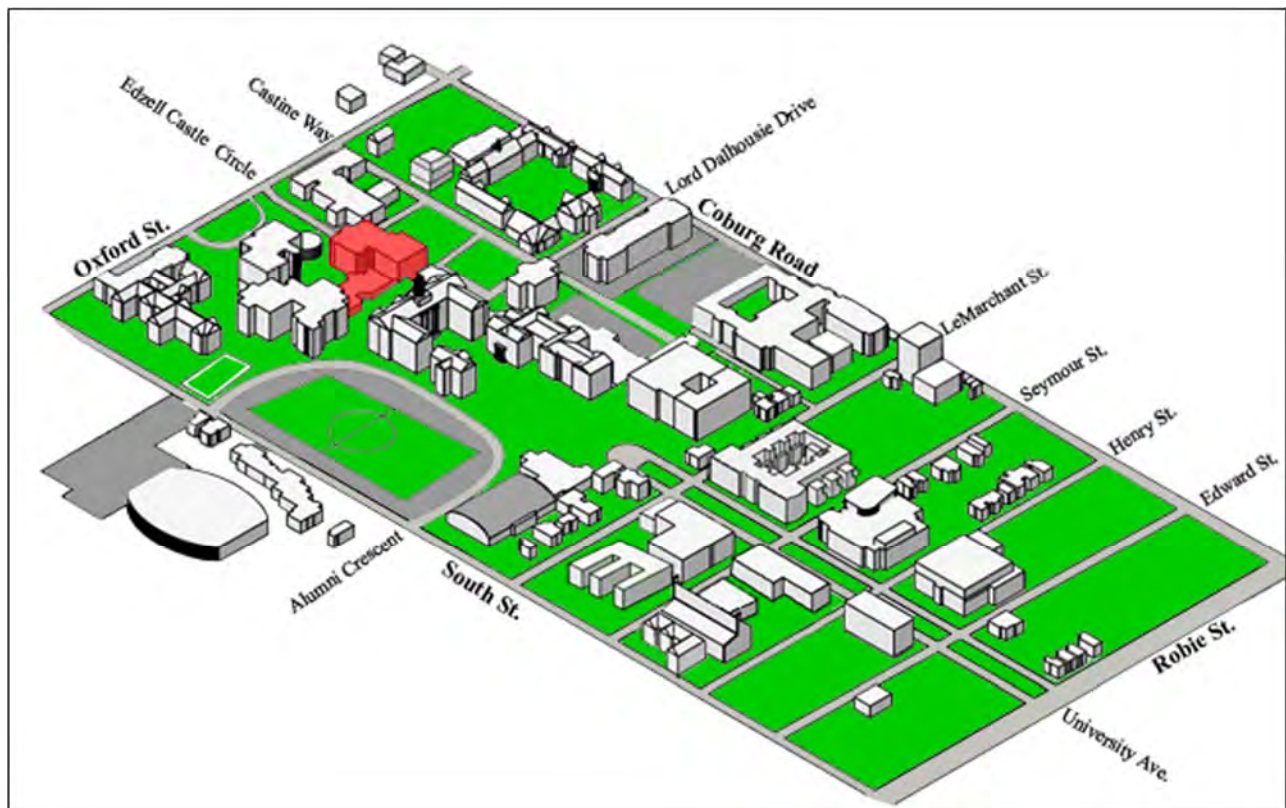




LIFE SCIENCES BUILDING



The Life Sciences Building (LSB) is located behind (west) of the University's Henry H. Hick's building (image at the top of this page) through which access to the building is available. Short Course 1 will be held in the building's Milligan Room located on the 8th floor.



The image is an aerial map of the University of York campus. It features several labels for buildings and landmarks. Two yellow circles highlight specific locations: one near the top left and another near the center left. Several buildings are outlined in red, including the Marion McCain Building, Student Union Building, Rislly Hall, Killam Ristro, and Lemarchant Residence. Other labels include Pharmacy, Coburg Coffee House, Topio's Pizzeria, Classic Fare Catering, Pizza Pizza, Subway, University Club, Thomas McCulloch Museum, and Shirreff Hall Cafeteria. The map also shows streets like Robie St, Edward St, Coburg Rd, and Lemarchant St.



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