Selected Core from the Albert Formation (Mississippian), Moncton Basin, Southern New Brunswick

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Abstract

Introduction

The Moncton Basin is located in the southeastern part of New Brunswick (Fig. 1) and has a long history of petroleum activity. In the area ~25 km S of Moncton there has been mining of solid bitumen, Albertite, at Albert Mines (1850's); minor and intermittent production of oil/gas at Dover and Saint-Joseph (1859 to 1905); and oil and gas production at Stoney Creek (1911 to 1991 - gas was piped to the city for ~80 years). Stoney Creek gas is sweet, but wet, and the oil (total in place ~2.1 x 10^6 m^3 with <5% recovered to date) is paraffinic with a pour point of over 7°C (45°F). Numerous appraisals of the oil shale in the area (e.g. Shell Albert Mines # 4 borehole) have also been undertaken periodically. In 2000, focus shifted 80 km west, where the McCully Gas Field (~1 TCF in place) was discovered, east of Sussex, by Corridor Resources Inc. and Potash Corporation of Saskatchewan (PCS). The A-67 discovery well (initial flow: 2.5 mcf p. day), and adjacent P-66 well currently produce gas for the PCS mill, but a link to the M&NE pipeline (Fig. 1) is planned to go into operation in late 2006. Approx. 17bcf (proven, ~120 bcf P2) remains in this production area (8% of the total joint venture area). Beyond the joint venture area, 8 km east of the currently producing wells, Well H-28 (EOG-Corridor) also intersected a higher pressure regime below 3km depth.

General lithostratigraphy

Almost all rocks in SE New Brunswick formed during the late Neoproterozoic to Palaeozoic (Fig. 2). Volcanic, metamorphic and metasedimentary rocks of early Devonian age and older are considered part of the 'basement' complexes. Strata of Late Devonian to Permian age, summarized most recently by St. Peter (1993), but currently being re-evaluated (e.g. St. Peter 2003), comprise 5 unconformity-bound sequences (Fig. 3). It is the lowermost (Famennian to Tournaisian) succession that is of most interest to explorationists, comprising red-bed strata that interfinger and enclose a unit of mostly grey coloured strata. The basal red-bed unit (Memramcook Fm.) consists mostly of conglomerate, together with gritstone, sandstone, and mudstone that is more common upsection. It is interpreted as an alluvial fan - braid-plain - floodplain succession. The grey-bed unit (Albert Fm.) is mostly of shale, but includes oil shale, sandstone, gritstone, conglomerate, and limestone of interpreted lacustrine and fluvial-(lacustrine) deltaic origin. It is host to the source and reservoir rocks of the McCully gas field, and the old Stoney Creek field. The medial Frederick Brook Mbr contains the main oil shale; reservoirs are in the sandstone of the underlying Dawson Settlement Mbr and overlying Hiram Brook Mbr. Red-beds that interfinger and conformably overlie the Albert Fm. are now assigned to the Bloomfield Fm. The formations of this lowermost sequence are classified as the Horton Gp.

Overlying cycles consist of the Sussex Gp (red-bed conglomerate, red shale and sandstone, and localized grey to red shale and evaporite of interpreted hyper-alkaline lake basin settings), the Windsor and Mabou groups (red-bed conglomerate and mudstone with several interfingering carbonate-evaporite cycles interpreted as marine transgressions of the 'Windsor' sea), the Cumberland Gp (grey- and red-bed sandstone and mudstone deposited in a fluvial-floodplain setting), and the Pictou Gp (red- and minor grey-bed sandstone, mudstone and coal of interpreted fluvial-floodplain-mire origin).

Structural setting

The basement complex was formed by Early Devonian time from the successive accretion of various terranes to the margins of Laurentia and Baltica as they converged and collided (Acadian Orogeny). Transpressional and transtensional motions, related to juxtaposition of the Meguma terrane (Gondwana) continued through the Late Devonian and into the Carboniferous. The stratigraphic succession of this time consists of regionally extensive, but relatively thin (typically less than 250 m in New Brunswick) deposits of Pennsylvanian-Permian age overlying a thick, but more localized succession of Late Devonian and Mississippian age strata. This latter succession is mapped along numerous linear belts in southern New Brunswick and northern Nova Scotia (Fig. 2). These belts follow the regional southwest-northeast fabric developed in the earlier Palaeozoic rocks as a result of collisional tectonics.

The nature and distribution of these linear Devonian-Permian belts has been best (but incompletely) explained by Bradley (1982) who related the features of intracontinental transform settings to the region. Following continental collision in the Devonian, the northern Appalachians were influenced by predominantly right-lateral strike-slip along the main transforms (Fig. 1). Adjacent to the boundary were contemporaneous areas of periodic transtension, forming pull-apart basins, and periodic transpression producing depositional unconformities and deformation. These smaller scale depositional basins (e.g. Moncton Basin, Cumberland Basin) were likely separate entities for most of late Devonian and (early to mid) Mississippian times. Transtension was accompanied by increased heat flow, locally with alkaline to tholeiitic volcanism. As movement along the main transform diminished, the dropping of isotherms caused periodic regional subsidence and the production of an enlarged sedimentary basin (the Pennsylvanian-Permian 'Greater Maritimes Basin'), which buried most of the rapidly sedimented pull-aparts with a blanket of more mature, more slowly deposited sediment (collectively, the Devonian-Permian basins are included in the 'Maritimes Basin Complex').

Late Devonian-Mississippian strata of southern New Brunswick are mostly preserved in the 200km long, northeast trending, wedge-shaped Moncton Basin, and in the adjacent Sackville Basin to the southeast and Cocagne 'Graben' to the northeast. The presently defined boundaries of these 'basins', being marked by faults that also delineate the aforementioned Neoproterozoic-Palaeozoic terranes, are not necessarily the location of the basin-bounding uplifts during sedimentation. The nature and timing of activity on these faults is only now being determined. For example (Park et al. 2006), the Indian Mountain deformed zone originated as a basement high 'separating' the Tournaisian Moncton and Cocagne basins, or at least it did so by the onset of deposition of the Sussex Group. In post-Sussex Group time the zone evolved into a fold-thrust belt, with subsequent deformation related to ENE-trending dextral strike-slip faults. In contrast, work south of Stoney Creek has resolved a late Tournaisian deformation event (equivalent to upper Sussex Group deposition) with the architecture of a fold-thrust belt (Park and St. Peter 2005). In the McCully area, two basin inversion events are documented within the Tournaisian, one at the end of the Horton Group, the other at the end of the Sussex Group (Wilson 2003). A later (end Mississippian) event folds Windsor Group evaporites and is associated with reverse/thrust faulting that likely includes allochthonous basement blocks (Keighley and Gemmell 2005).

Albert formation sedimentology and lithofacies models

The Albert Fm. comprises a wide variety of lithofacies that have long been considered indicative of a lacustrine basin: alluvial fan and fan delta conglomerates, fluvio-deltaic sandstone and pebbly sandstone, forest and floodplain palaeosols, sheetflood sand- and siltstone, carbonate (algal) and clastic mudflat, lake-shoreface carbonate and sandstone, and deep lake, variably organic and dolomitic mudstone-shale - see Keighley and Brown (2005) for references and brief comment regarding potential marine incursions. Most of the above-named lithofacies are interpreted from the core from Shell Albert Mines #4 and EOG-Corridor McCully H-28 (Figs. 4 - 6), which are on display.

Three recurring lacustrine lithofacies associations have long been modelled for all lake basins at the scale of metres to hundreds of metres. Olsen (1990) explained their occurrence as reflecting the interplay of basin morphology, climate, and time. Collectively, these factors influenced the magnitude and frequency of lake-level change. Predominantly open lakes over time result in fluvial-lacustrine facies associations, predominantly closed lakes over time produce evaporative facies associations, and lakes that fluctuated between open and closed produce profundal facies associations (Fig. 7). Carroll and Bohacs's (1999) equivalent terms are 'underfilled', 'overfilled', and 'balanced fill' successions. On a similarly broad scale, a typical lithofacies succession for all long-lived (>M.yr), actively subsiding, intermontane basins has been identified (Fig. 8; Lambiase 1990; Keighley et al. 2003). During the initial (stage 1) 'growth phase' of the basin, accommodation space develops at a higher rate than supplied sediment can infill this volume, and predominantly coarse-grained alluvial deposits initially infill major topographic lows until the basin develops internal drainage. At this point (stage 2), localized alluvial deposits may continue to form around the basin margin, but fine grained lacustrine deposits tend to dominate in the basin centre. Eventually, due to a reduction in tectonism, or because of increasing sediment supply, there is a net reduction in accommodation. Where a deep basin is present, thick delta front and delta top sediment packages may develop (stage 3) as it infills. As the deltas extend across the infilling basin, typically in an axial direction, floodplain and fluvial deposition expands landward of the deltas (stage 4). On a temporal scale, basin fill may be relatively rapid compared to the period of basin growth.

With respect to the Albert Fm., the core from Albert Mines (Dawson Settlement Mbr, Fig. 5) most likely represents stage 1 - early stage 2, since the main oil shale unit overlies this interval. As such, sandbodies are likely locally sourced and mineralogically immature. Core from McCully (Hiram Brook Mbr, Fig. 6) lies above the main oil shale interval, and likely represents part of the infilling (stage 3) phase of the lake. The cored sandbodies are considered part of an axial drainage system, sourced external to the basin and thus finer grained and mineralogically more mature. Preservation of shoaling upward successions and thick successions of often slumped mudstone/oil shale in outcrop and core (e.g. Keighley & Mohan 2006) suggests fairly continuous and deep lakes with persistence of a significant subaqueous gradient adjacent to the footwall block. Palaeocurrents indicate mostly an easterly flow and thus axial infilling of the basin from the west (slumps likely propagated in sediments accumulating adjacent to the footwall block to the south). In contrast, the sharp base to the sandstone package in core at Albert Mines #4 (Fig. 4) may indicate the presence of an unconformity (e.g. incised valley). Together with the diversity of fluvial-lacustrine and palludal lithofacies associations in core, and other known lithofacies successions in outcrop and wireline data, the lake basin that accumulated Albert Fm. strata is considered to have been predominantly overfilled, with infrequent balanced fill (Fig. 9).

Known petroleum systems

The McCully field, covering over 11,400 hectares, is a large anticlinal structure (progressively formed by successive Carboniferous deformation events) with four way closure. Intraformational faults, stratigraphic pinch outs, and the base Sussex Gp unconformity are likely also factors in trapping the gas. To date, drilling has been concentrated on the crest and northwest limb (Fig. 4), and wells have only penetrated to the Frederick Brook Mbr (the source rock). Production is currently from two Hiram Brook Mbr sandstone packages, several metres thick, at ~2.3 km depth, with gas pressure >500 psi above hydrostatic for this depth, indicating a >500 m gas column. Porosities (av. 8%) and permeabilities are low, because of the fine grain size and high capillary pressure. Low thermal gradients, coupled with the overpressures, can lead to hydrate formation. Furthermore, the sandstone is desiccated: in having very low water saturation (10-20%), irreducible water (Sw) capacity is much higher, meaning that any added water produces phase blocking.

Production data from the old Stoney Creek field has been poorly recorded but was from a south-dipping Hiram Brook Mbr (possibly also Dawson Settlement Mbr) sandstone lenses (up to 30 m thick) over a stratigraphic interval of ~800 m that covered 150 hectares (St. Peter & Spady 2003). Porosities average 12% and S_w is ~15%. The trap is formed by the unconformity with overlying Mississippian tectonic cycle 3 redbeds and the source rock is the Fredericks Brook Mbr.

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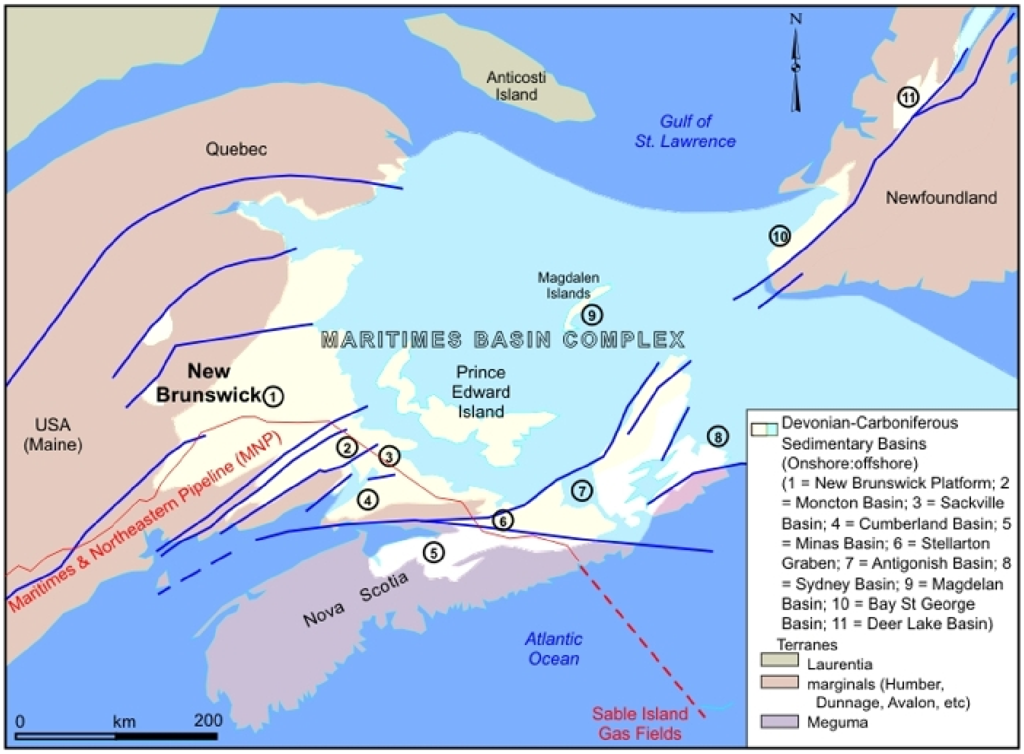


Figure 1. General location map, showing major structural components of the Maritimes Basin Complex and location of the Maritimes and Northeastern Pipeline.

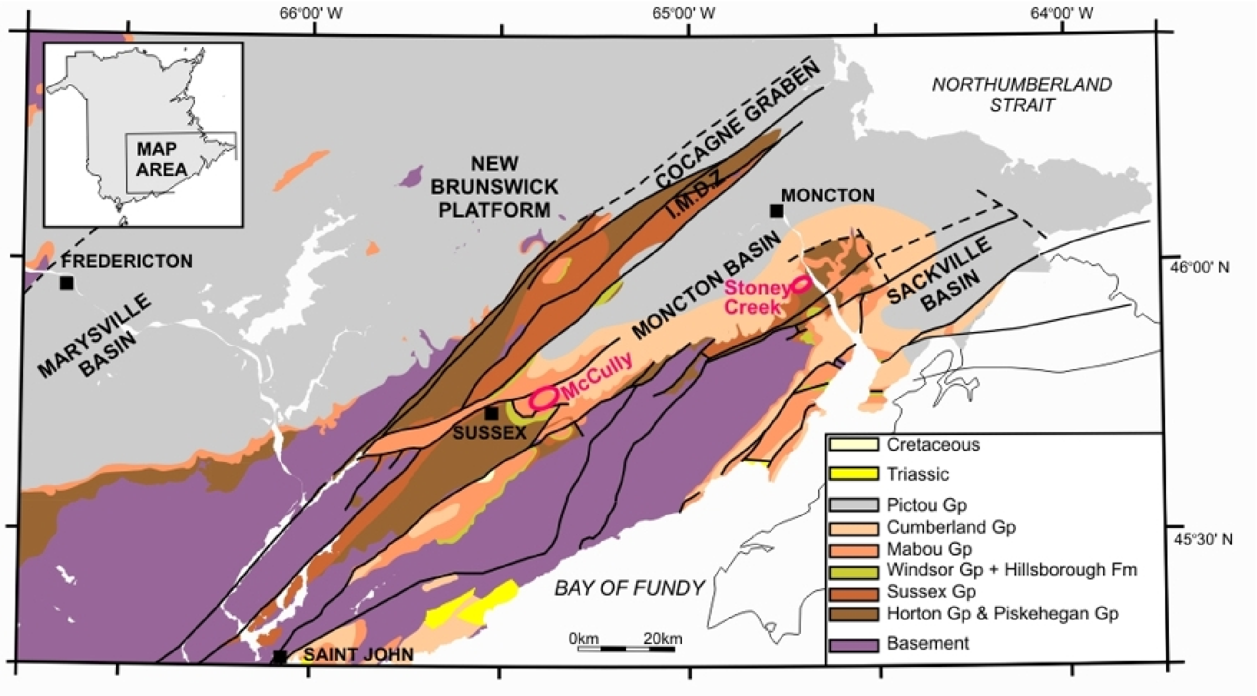


Figure 2. Major Upper Palaeozoic structural elements in SE New Brunswick (IMDZ = Indian Mtn Deformed Zone).

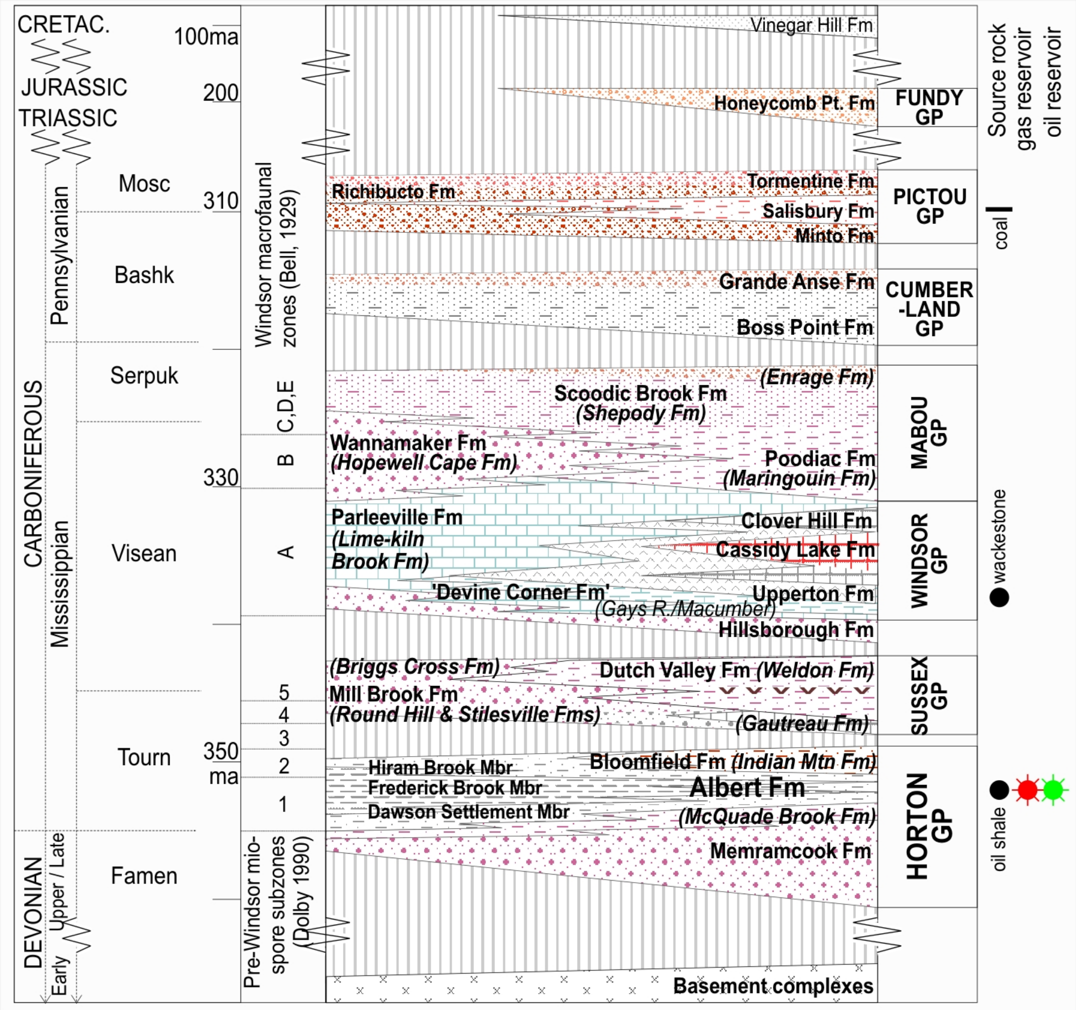


Figure 3. Stratigraphy of the Moncton Basin.

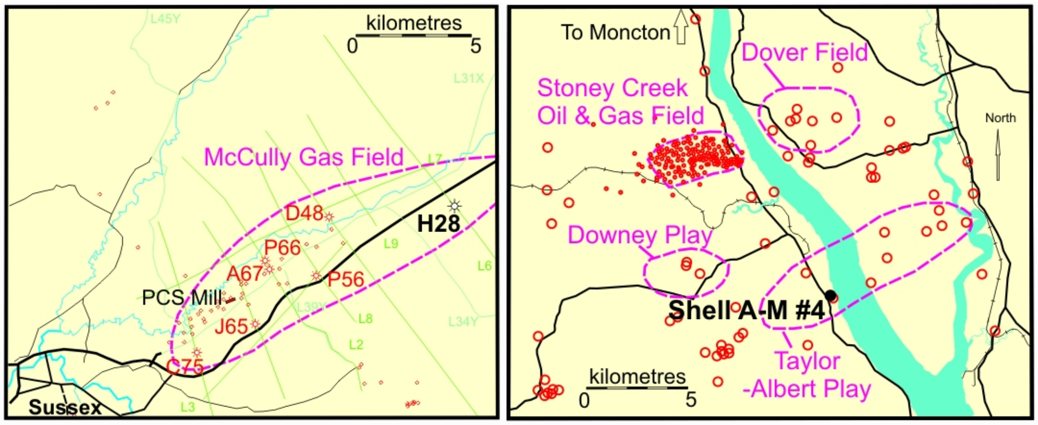
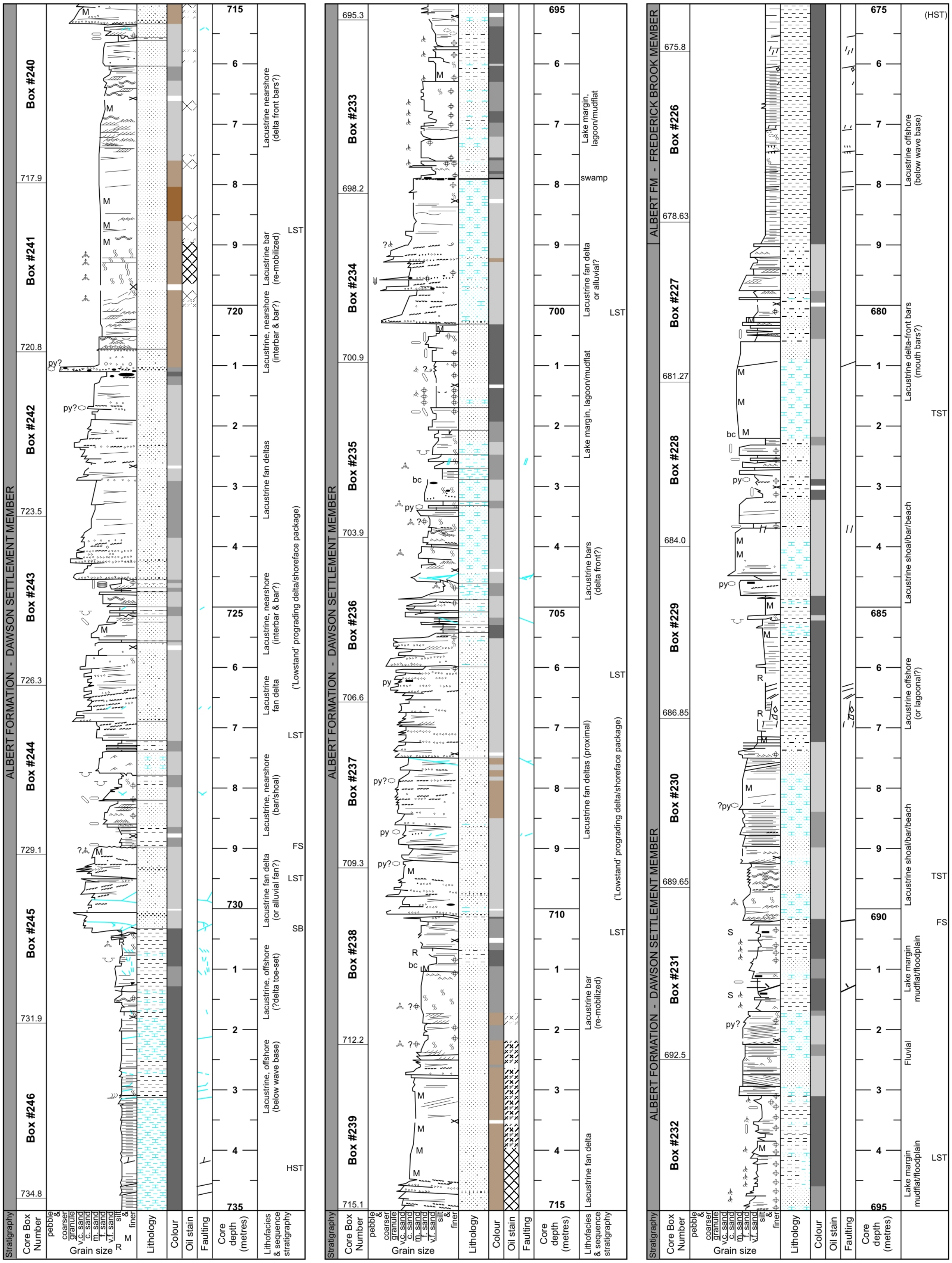
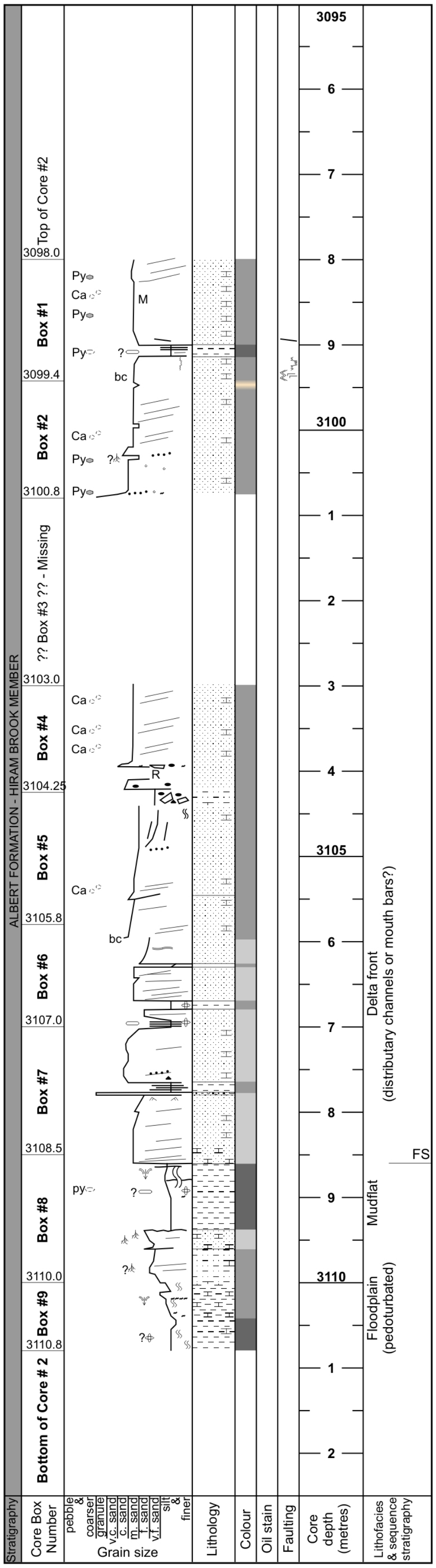
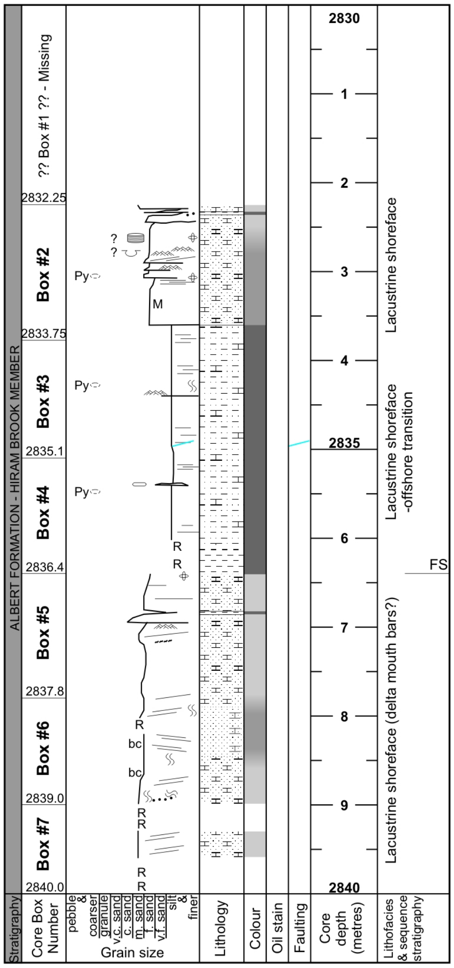


Figure 4. Location of the Shell Albert Mines #4 and McCully H28 wells.


ALBERT FORMATION - DAWSON SETTLEMENT MEMBER
Box #240
Box #241
Box #242
Box #243
Box #244
Box #245
Box #246
717.9
720.8
723.5
726.3
729.1
731.9
734.8
715
720
725
730
735
py?
M
R
Lacustrine nearshore (delta front bars?)
Lacustrine bar (re-mobilized)
Lacustrine, nearshore (interbar & bar?)
Lacustrine fan deltas
Lacustrine, nearshore (interbar & bar?)
Lacustrine fan delta
Lacustrine, nearshore (bar/shoal)
Lacustrine fan delta (or alluvial fan?)
Lacustrine, offshore (?delta toe-set)
Lacustrine, offshore (below wave base)
LST
('Lowstand' prograding delta/shoreface package)
LST
FS
LST
SB
HST
Stratigraphy
Core Box Number
pebble & coarser
granule
v.c. sand
c. sand
m. sand
f. sand
v.f. sand
silt & finer
Grain size
Lithology
Colour
Oil stain
Faulting
Core depth (metres)
Lithofacies & sequence stratigraphy
ALBERT FORMATION - DAWSON SETTLEMENT MEMBER
Box #233
Box #234
Box #235
Box #236
Box #237
Box #238
Box #239
695.3
698.2
700.9
703.9
706.6
709.3
712.2
715.1
695
700
705
710
715
py
bc
Lake margin, lagoon/mudflat
swamp
Lacustrine fan delta or alluvial?
Lake margin, lagoon/mudflat
Lacustrine bars (delta front?)
Lacustrine fan deltas (proximal)
Lacustrine bar (re-mobilized)
Lacustrine fan delta
LST
LST
('Lowstand' prograding delta/shoreface package)
LST
ALBERT FM - FREDERICK BROOK MEMBER
ALBERT FORMATION - DAWSON SETTLEMENT MEMBER
Box #226
Box #227
Box #228
Box #229
Box #230
Box #231
Box #232
675.8
678.63
681.27
684.0
686.85
689.65
692.5
675
680
685
690
695
(HST)
Lacustrine offshore (below wave base)
Lacustrine delta-front bars (mouth bars?)
TST
Lacustrine shoal/bar/beach
Lacustrine offshore (or lagoonal?)
Lacustrine shoal/bar/beach
TST
FS
Lake margin mudflat/floodplain
Fluvial
Lake margin mudflat/floodplain
LST





KEY TO CORE LOGS

CONTENT
An = anhydrite; Ca = carbonate; gy = gypsum; py = pyrite; s = silt; sid = siderite
Pebbles/granules
Quartz/feldspar clastic limestone
Calcareous fossils (in general)
Organic matter
plant detritus (in general) fossil logs
coal

bc = broken core
R = rubbled core
= gap in core record

DEPOSITIONAL SEDIMENTARY STRUCTURES
M Massive (structures absent/destroyed/not visible)
Oriented content - structure not discernable (pebbles, organic)
Cross-strata (non-diagnostic - typically low-angle)
Small scale troughs (< 25cm thick)
pebble-lagged troughs ripple-filled troughs
Sigmoidal
Tabular, asymptotic based
Tabular, planar based
Swaley / hummocky (small scale)
Ripple cross-laminae (non-diagnostic)
asymmetric climbing asymmetric, non-climbing
symmetric (wave rippled)
Parallel lamination

SYN- TO POST-DEPOSITIONAL STRUCTURES
Brecciated sediment
Faulting (or fractures, displacement not visible)
silt filled Ca filled Si filled
slickensided surfaces
Stylolites
Concretions (general cemented zones)
nodule (regular shaped concretion)
Cracks (general)
synaeresis cracks desiccation
Soft-sediment deformation (general)
convolutions, pipes, sand volcanoes
loads, pseudonodules
overturned bed (not structural folding)
mudstone clastiforms
Bioturbation
horizontal burrows in general
vertical/vertical component burrows in general
vertical displacements
Meniscate Spreiten
vertical fabric (uncertain roots/burrows)
Roots

SPECULATIVE SEQUENCE STRATIGRAPHY
SB Sequence boundary **FS** (Maximum) Flooding Surface
(L/T/H) ST (Lowstand/Transgressive/Highstand) Systems Tract

Figure 5. (Previous Page) & 6. Sedimentary logs of core from 735 - 675 m (Shell Albert Mines #4 well -from Keighley 2000) and 3110.8 - 3098 m and 2840 - 2832.5 m (McCully H-28 well).

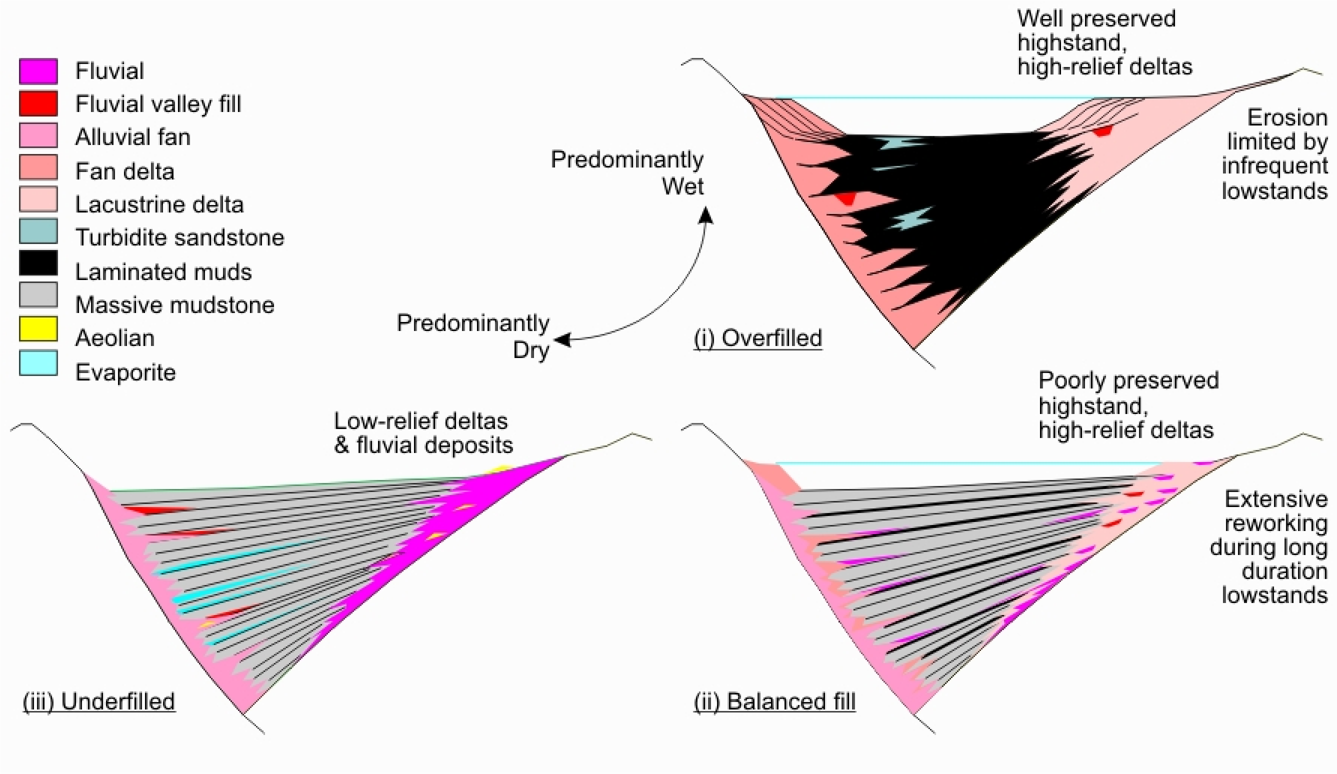


Figure 7. Climate influence on lake -level curves and sequence architecture for early rift phases in i) high-latitude, persistently wet (overfilled) systems, ii) tropical (balanced) systems, and iii) sub-tropical, semi-arid climate (underfilled) systems (From Keighley & Brown 2005, after Olsen 1990).

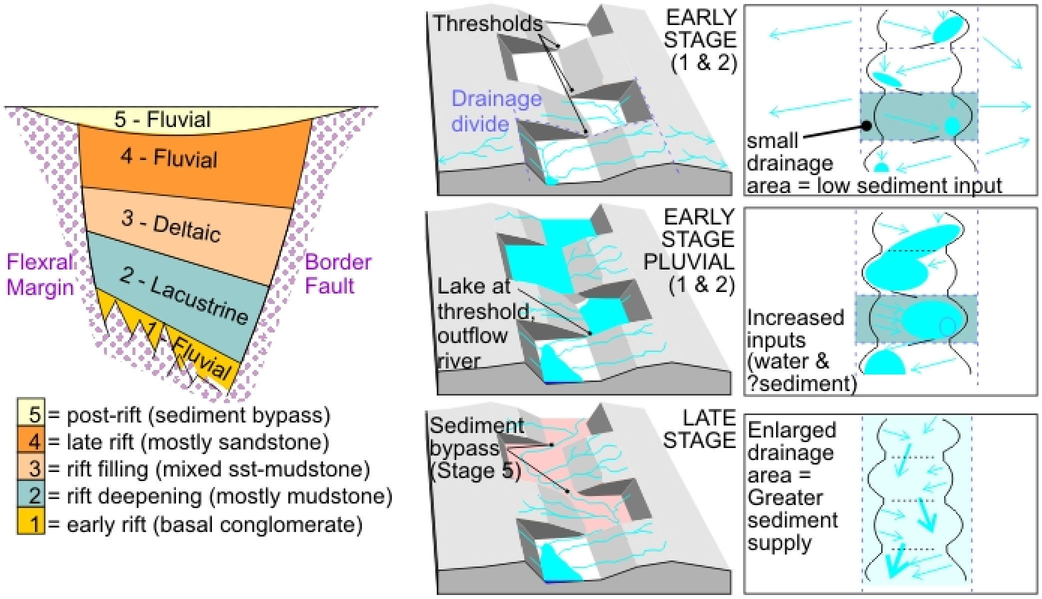


Figure 8. Low resolution tectonic sequences. A) Cartoon cross-section across a rift basin, showing Lambiase's (1990) 5 stages of basin fill. B to D) Models for lake basins at different stages of fill (From Keighley & Brown 2005).

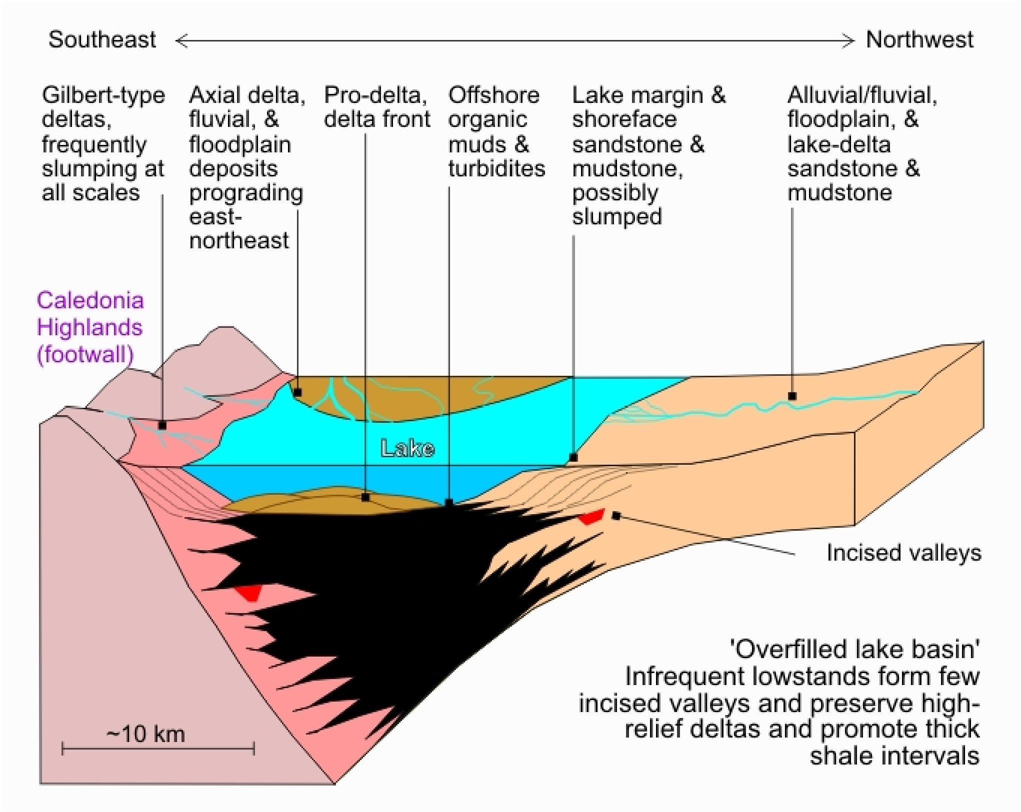


Figure 9. Suggested model for Albert Formation lakes in southern New Brunswick (from Keighley & Brown 2005).