Changes in Depositional Style between the Underfilled and Overfilled Portions of a Foreland Basin: An Example from the Western Canada Sedimentary Super Basin

CSPG
Canada's Energy Geoscientists

BASS Division Presentation
Feb 13 2019

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Zaitlin Geoconsulting Ltd.

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Outline

- Introduction
- WCSB Geologic Setting
- Underfilled vs. Overfilled Foreland Basin
- Incised Valley and Shoreline styles
- Summary and Conclusions
- Acknowledgements

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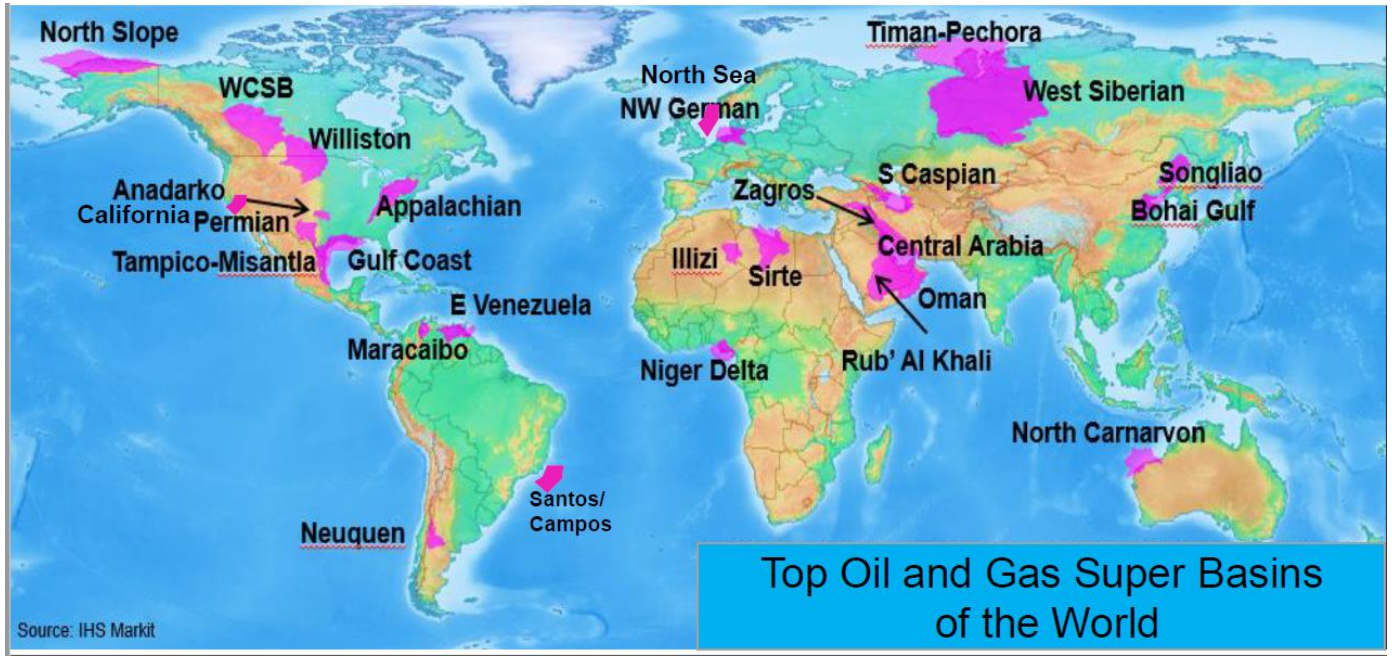
Super-basins

Location of 25 Superbasins that meet the following Criteria:

- **More than 5 billion Boe cumulative production**
- **More than 5 billion Boe remaining production**
- **Multiple source rocks – petroleum systems**
- **An assemblage of conventional, shale (continuous) and tight-non-continuous reservoirs**
- **Stacked pays**
- **Established infrastructure – access to markets**
- **Established service sector & supply chains**

Western Canada Sedimentary Basin meets Criteria



WCSB contains both a Deep Basin and Oil Sands component, plus an assemblage of conventional, shale (continuous) and tight reservoirs

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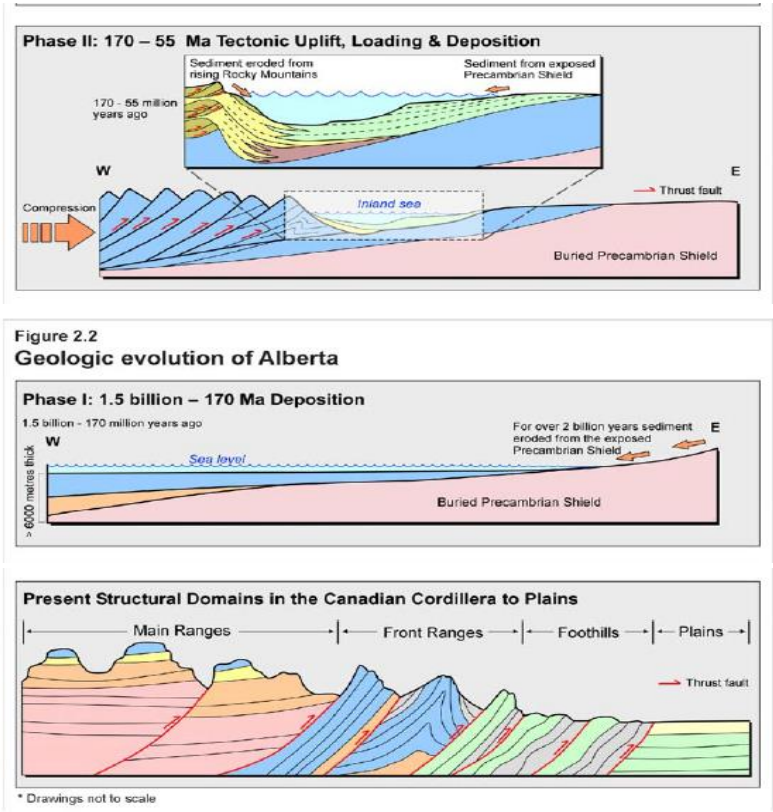
Western Canada Sedimentary Basin Tectonic Evolution

Foreland Basin

Pre-Foreland Basin



- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado

- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan
- Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg

ERCB ST-98-2011

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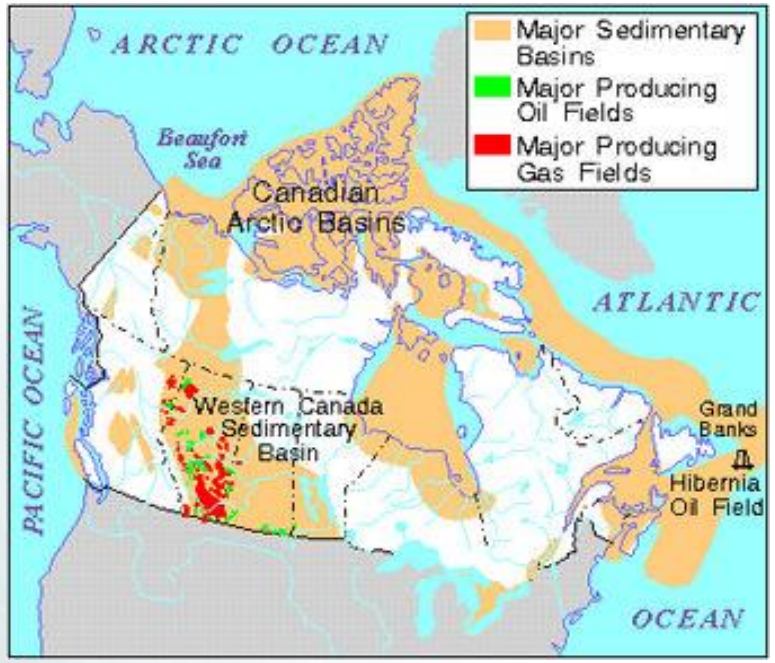
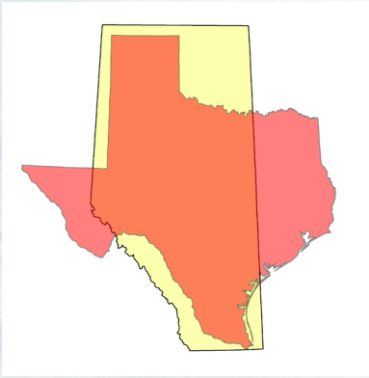
Oil and Gas in the WCSB



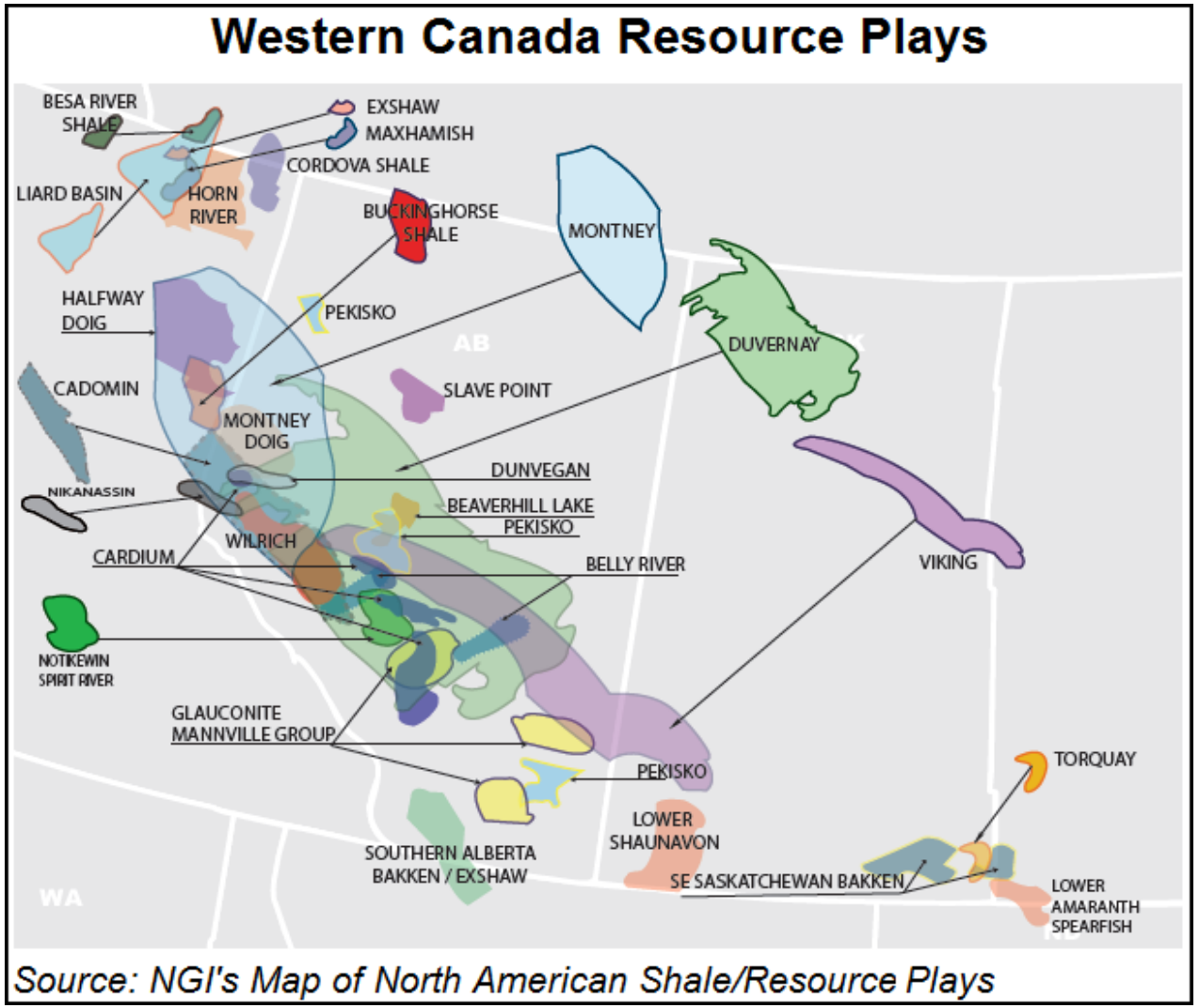


Alberta

Area: 661,848 km^2

Texas

Area: 696,241 km^2



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Key - Major Source Rocks in the WCSB

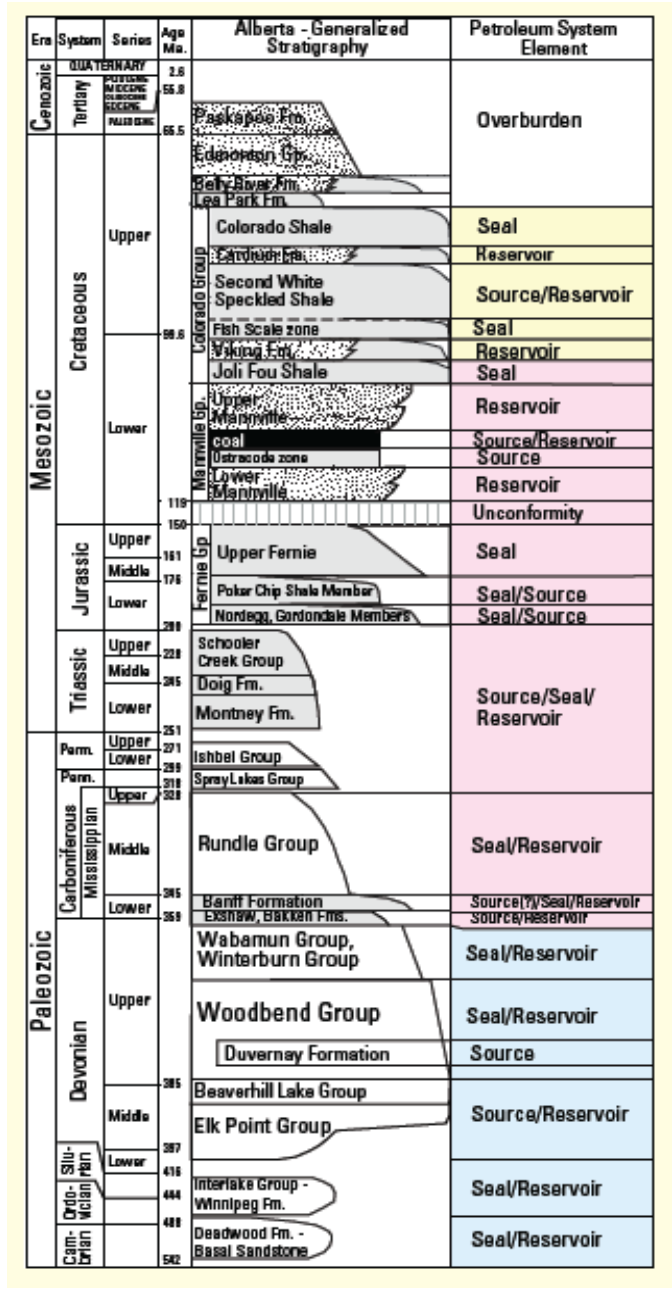
- 16+ Source Rock Intervals on WCSB
- Key Source Rocks

Foreland Basin

- SWS
- Colorado Group Source Rocks
  (e.g. 1st Specks, Fish Scales, Joli Fou)
- Ostracod
- Fernie/Poker Chip
- Nordegg

Pre-Foreland Basin

- Pardonet
- Baldonnel
- Doig Phosphate
- Montney
- Banff
- Exshaw
- Calmar/Ireton
- Duvernay
- Elk Point



USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012

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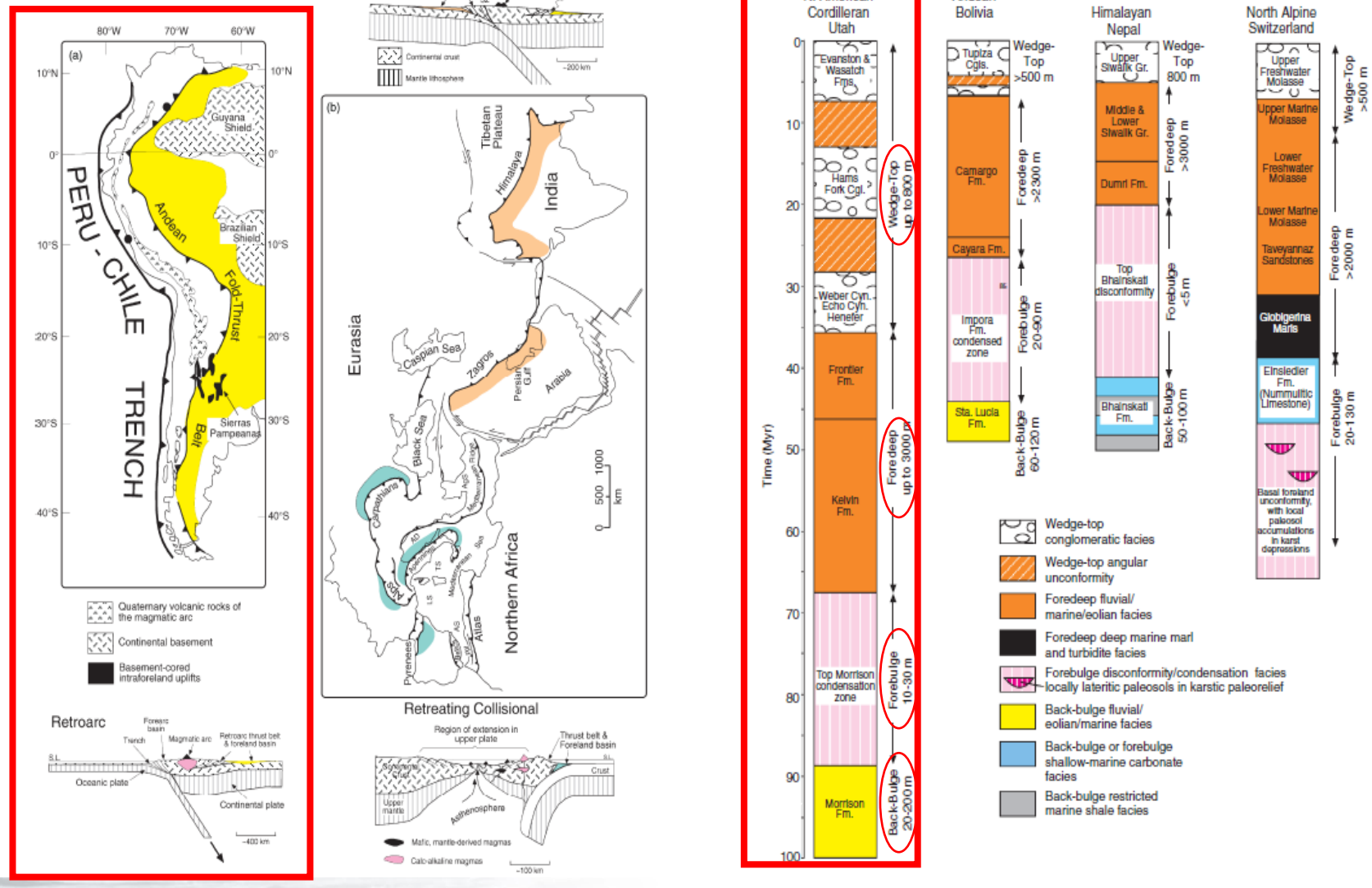
Types of Foreland Basin Systems



Foreland Basins

1. **Retroarc Basins**
   - ***N. American Cordilleran - WCSB***,
   - S. American – Andean – Bolivia
2. **Collisional Basins**
   - Himalayan – Nepal
3. **Retreating Collisional Basin**
   - North Alpine – Switzerland

Four Zones in a Retroarc Foreland Basin

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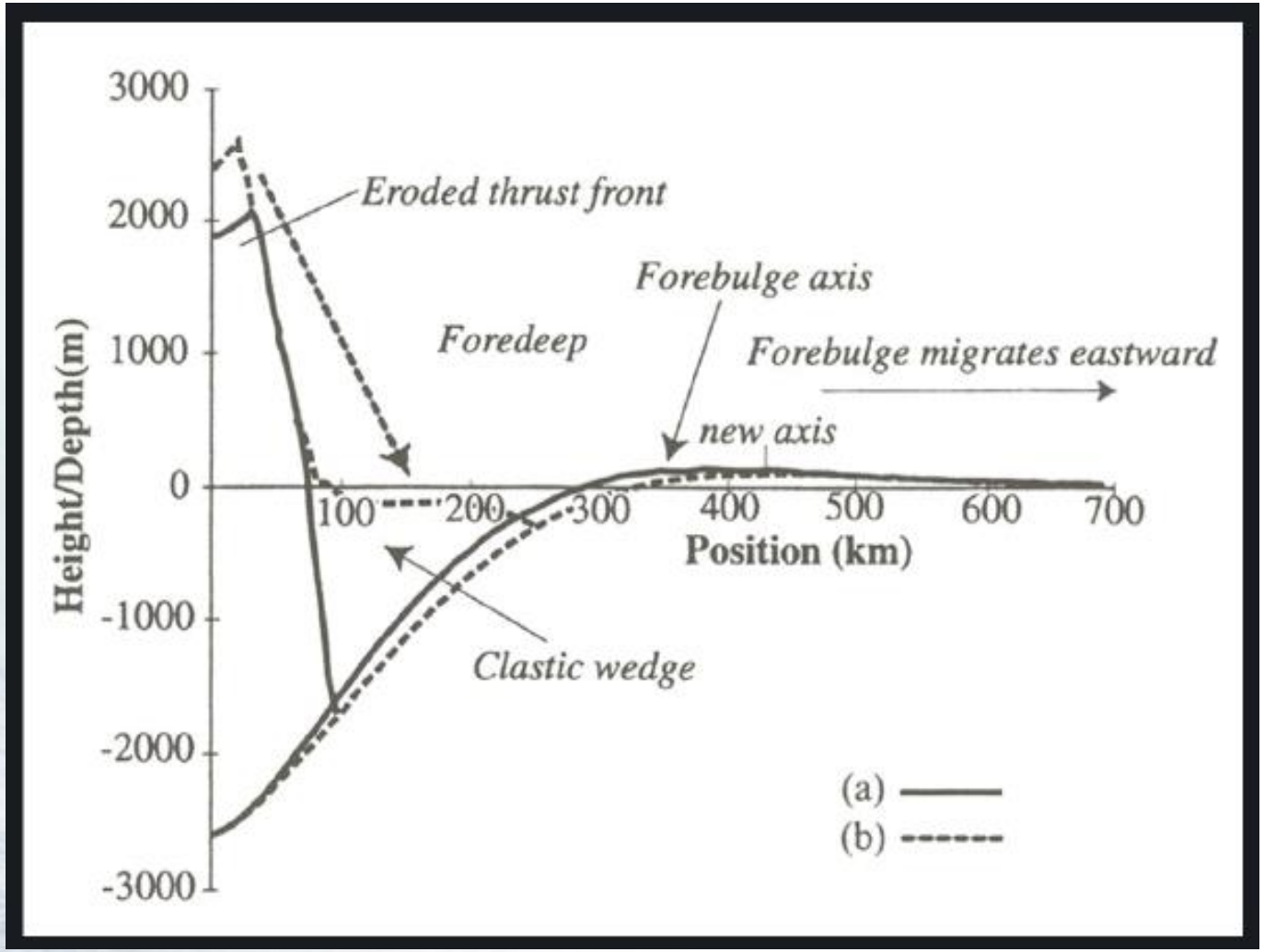
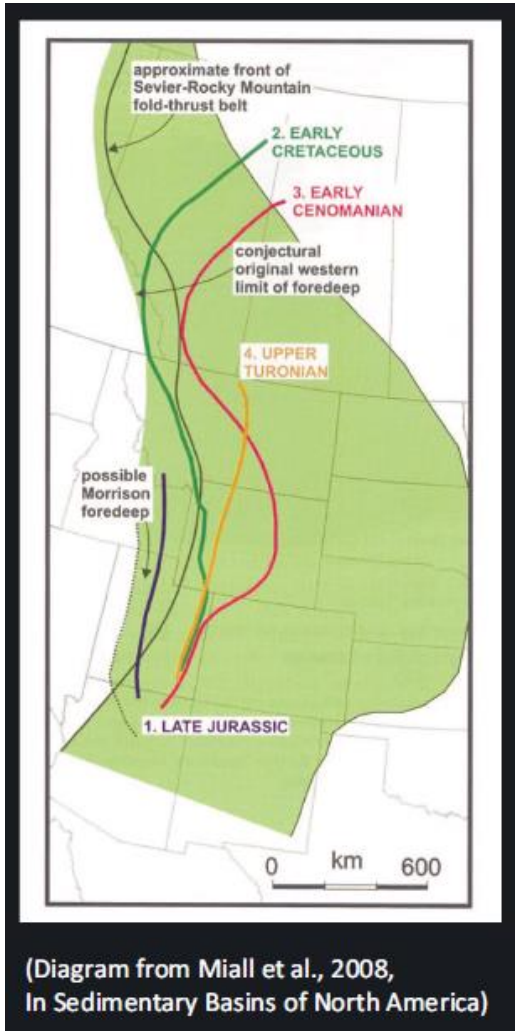
WCSB Foreland Basin – Forebulge Migration



DeCelles, 2012



(Diagram from Miall et al., 2008,
In Sedimentary Basins of North America)

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Foreland Basin

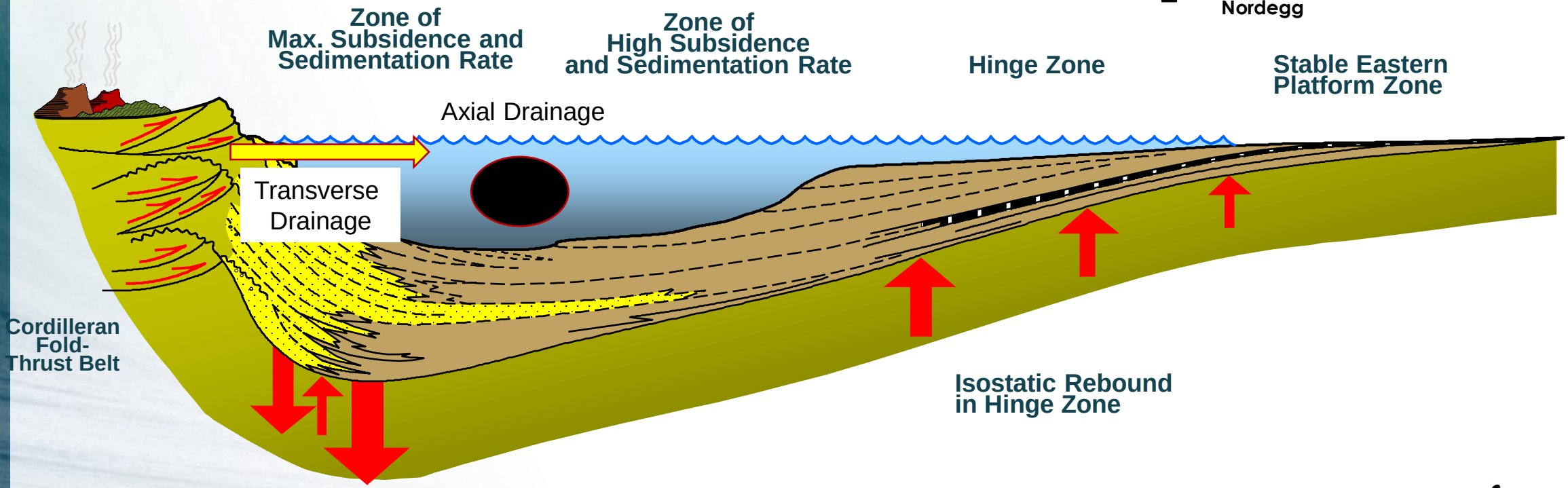
Axial Drainage vs. Transverse Drainage
Underfilled FB vs. Overfilled FB

Overfilled Foreland Basin

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado

Underfilled Foreland Basin

- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan
- Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg



modified after Kauffman, 1984

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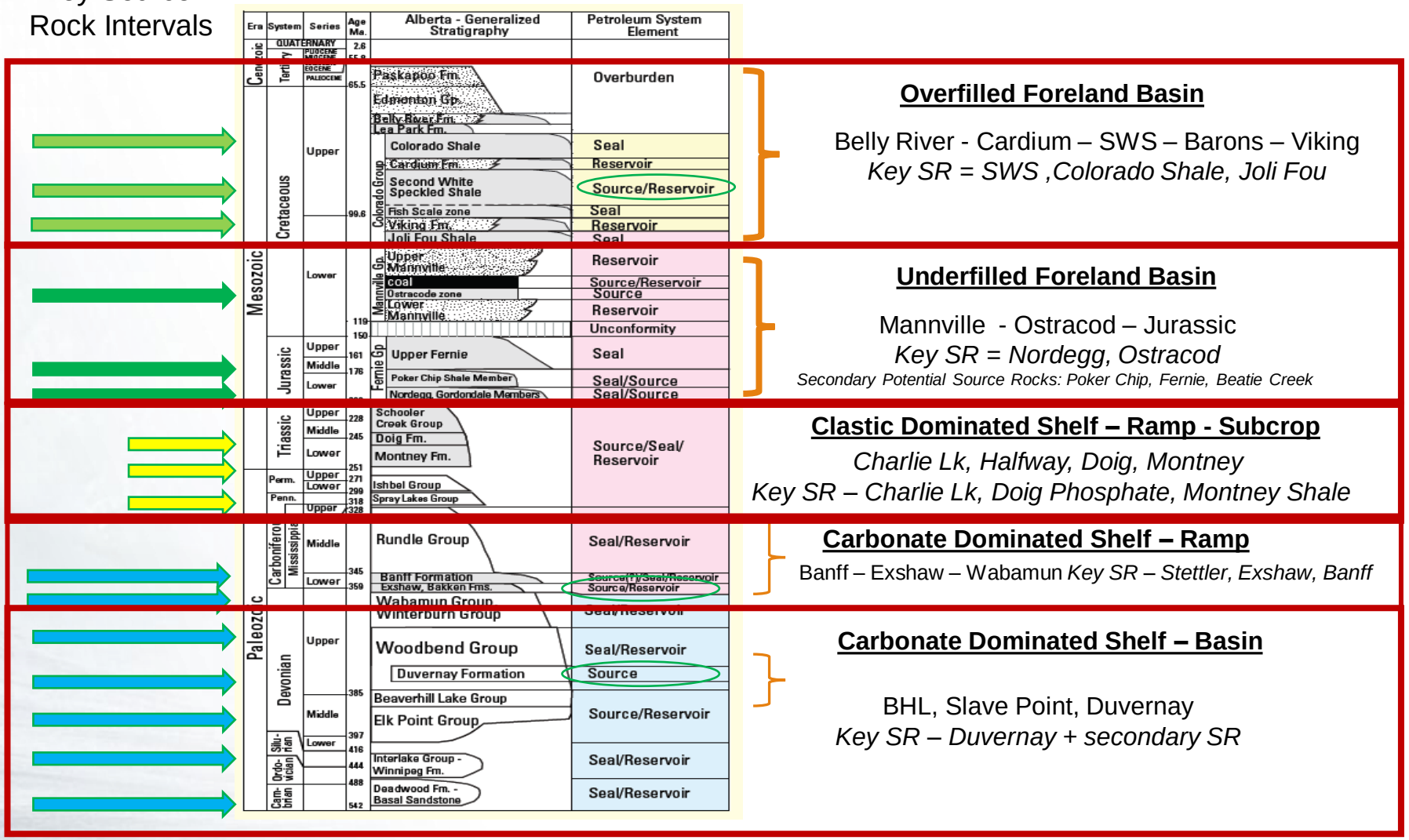
WCSB - Multiple Hydrocarbon Systems (5)

Key Source Rock Intervals

Foreland Basin

Pre-Foreland Basin



Overfilled Foreland Basin — 5

Belly River - Cardium – SWS – Barons – Viking

Key SR = SWS ,Colorado Shale, Joli Fou

Underfilled Foreland Basin — 4

Mannville - Ostracod – Jurassic

Key SR = Nordegg, Ostracod

Secondary Potential Source Rocks: Poker Chip, Fernie, Beatie Creek

Clastic Dominated Shelf – Ramp - Subcrop — 3

Charlie Lk, Halfway, Doig, Montney

Key SR – Charlie Lk, Doig Phosphate, Montney Shale

Carbonate Dominated Shelf – Ramp — 2

Banff – Exshaw – Wabamun *Key SR – Stettler, Exshaw, Banff*

Carbonate Dominated Shelf – Basin — 1

BHL, Slave Point, Duvernay

Key SR – Duvernay + secondary SR

USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012

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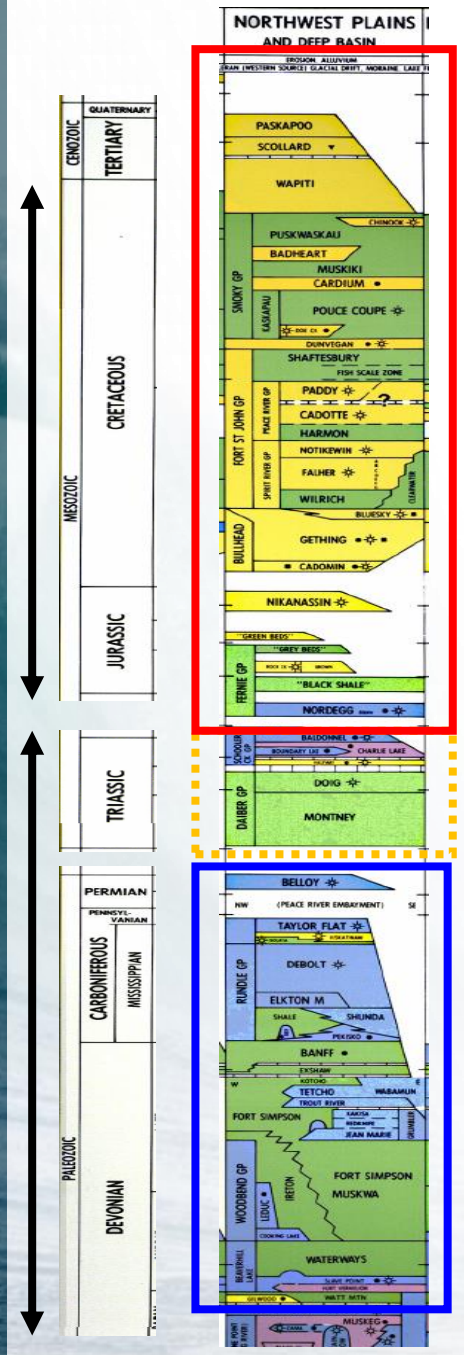
3 Stacked Deep Basin Systems

Pre- Foreland Basin

Foreland Basin



Jurassic - Cretaceous
Foreland
"Deep Basin"

Overfilled Foreland Basin

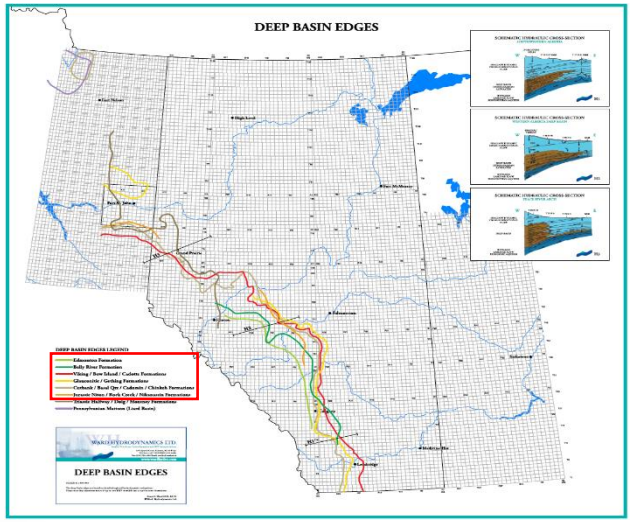
- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado

Underfilled Foreland Basin

- U Mannville
- Spirit River
- (Wilrich/Falher/Notikewan
- Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Rock Creek
- Nordegg

Triassic
"Deep Basin"

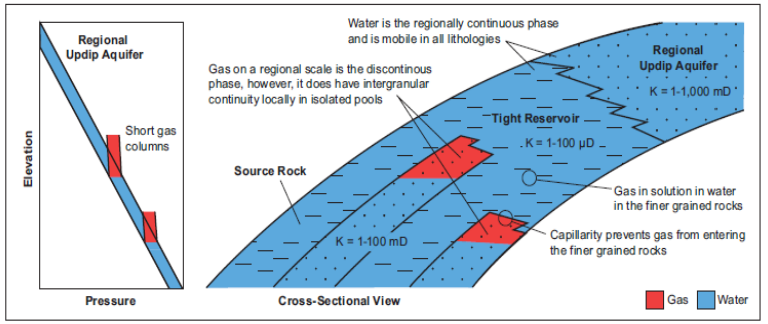
Mississippian – Devonian
"Deep Basin"



Ward, unpublished

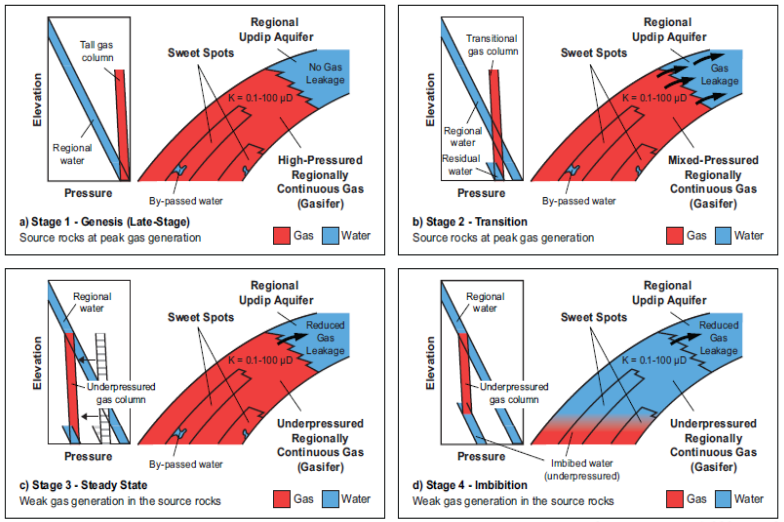
Techniques for Defining the Deep Basin

Deep Basin Gas - Schematic Reservoir Model



Source: Burnie et al, 2005, Fig. 1

Deep Basin Gas - Development Stages of a Regional Low Permeability Gas System



Source: Burnie et al, 2005, Fig. 3

Burnie et al., 2005

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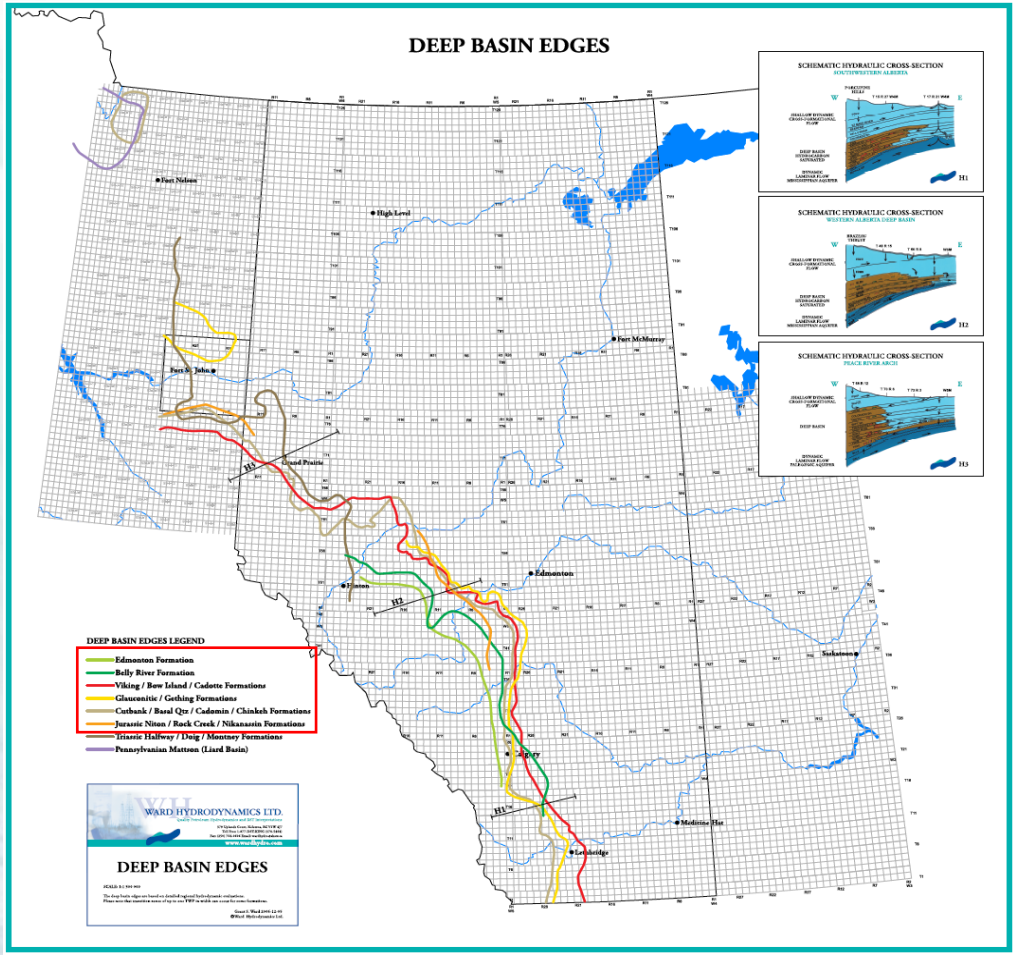
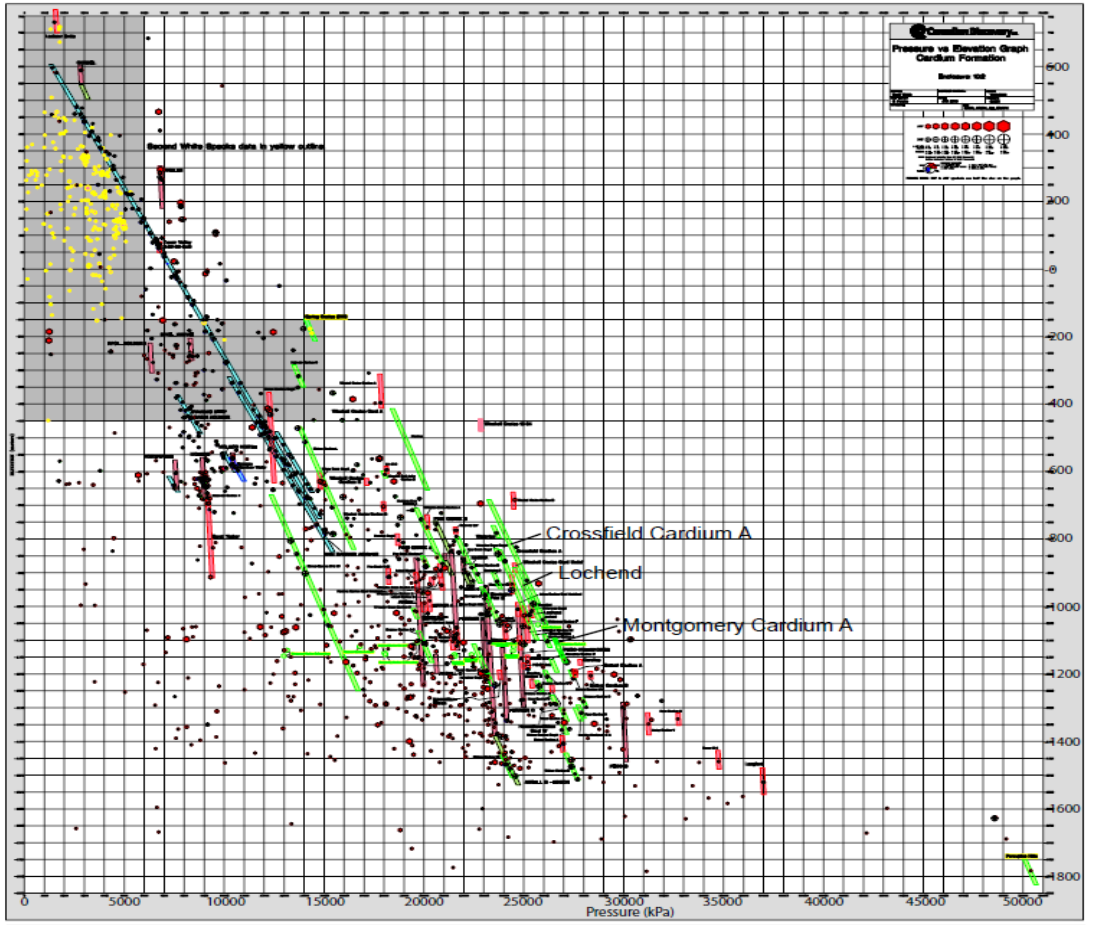
Techniques for Defining the Deep Basin

WCSB Deep Basin Edges



Cardium –Pressure vs. Elevation



Source: Reservoir Characterization and Mapping of the Cardium Formation T.1-27, R.22W4-5W5, Study 2012, Canadian Discovery

Ward

- Each Fm/Gp has a unique updip Deep Basin limit
- Jurassic Cretaceous Updip limit can be a 30-50 mile wide zone

CDD

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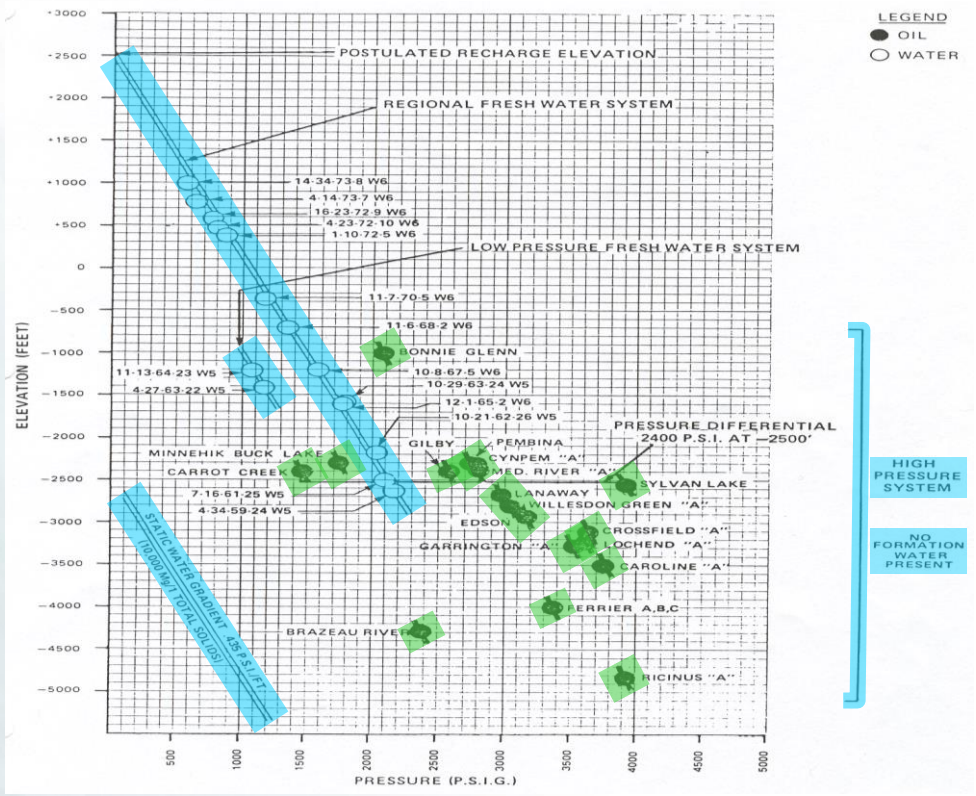
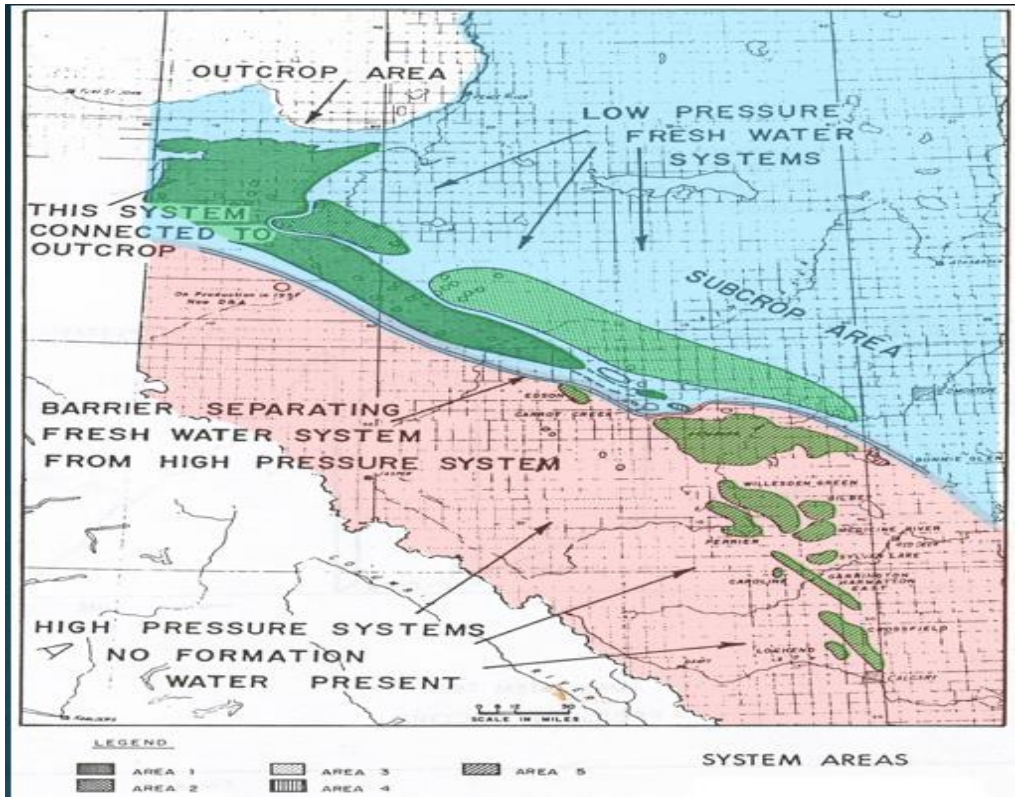
Deep Basin Concept was an Oil Concept
Cardium Formation – Pressure Elevation Graph





Pendergast, 1969, CWLS V.1, No 1, Pg 1

Pendergast (late 1960's with Amoco) worked up Tight Oil Deep Basin concept from the Cardium Deep Basin Tight Oil Concept then transferred to DJ Basin and BCG Systems

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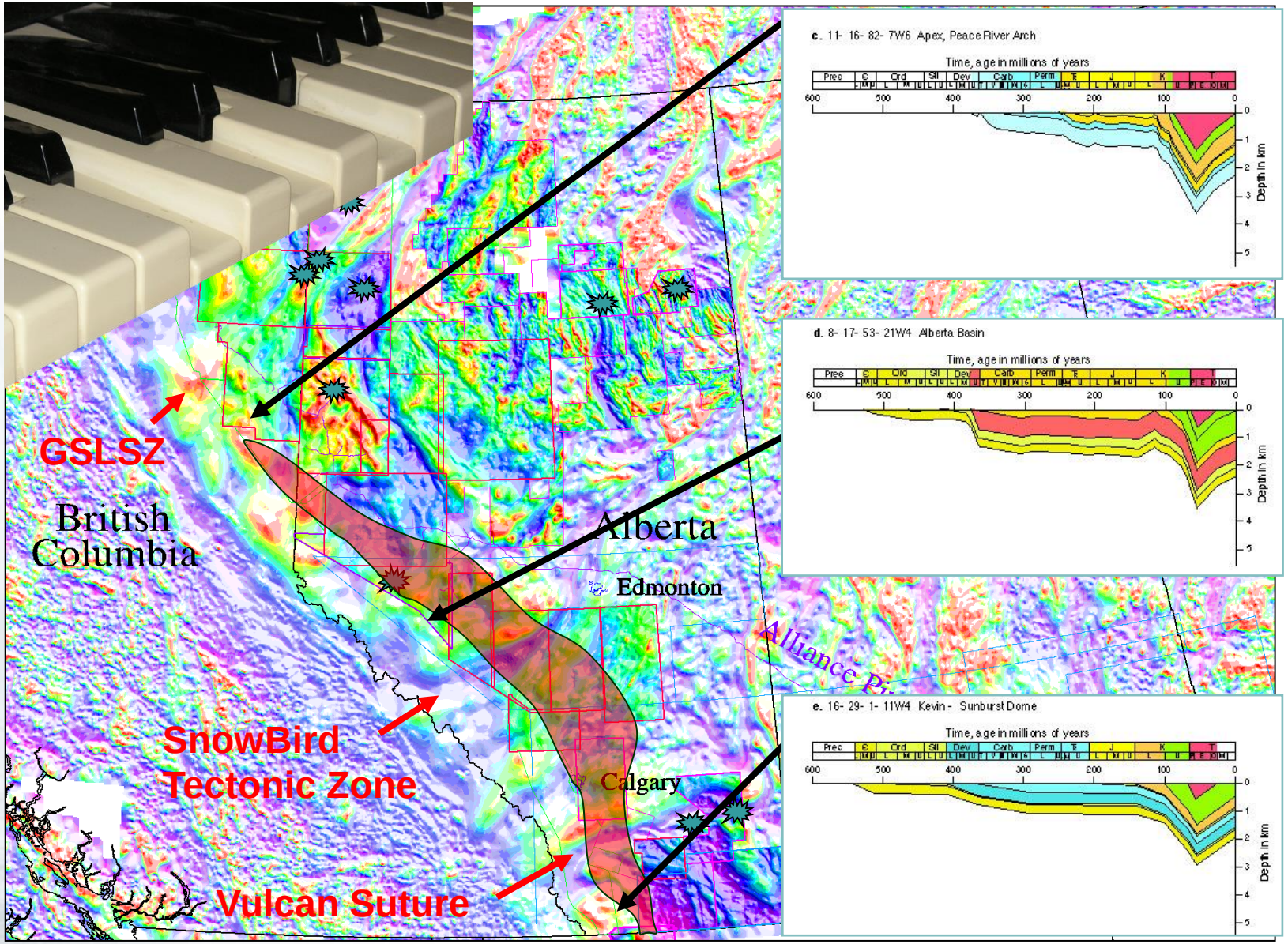
Burial History Curves

Compartmentalization of the WCSB Shear Zone "Piano Key" Effect



WCSB Atlas, 1994; Pierce and Griffiths, 2003, 2005

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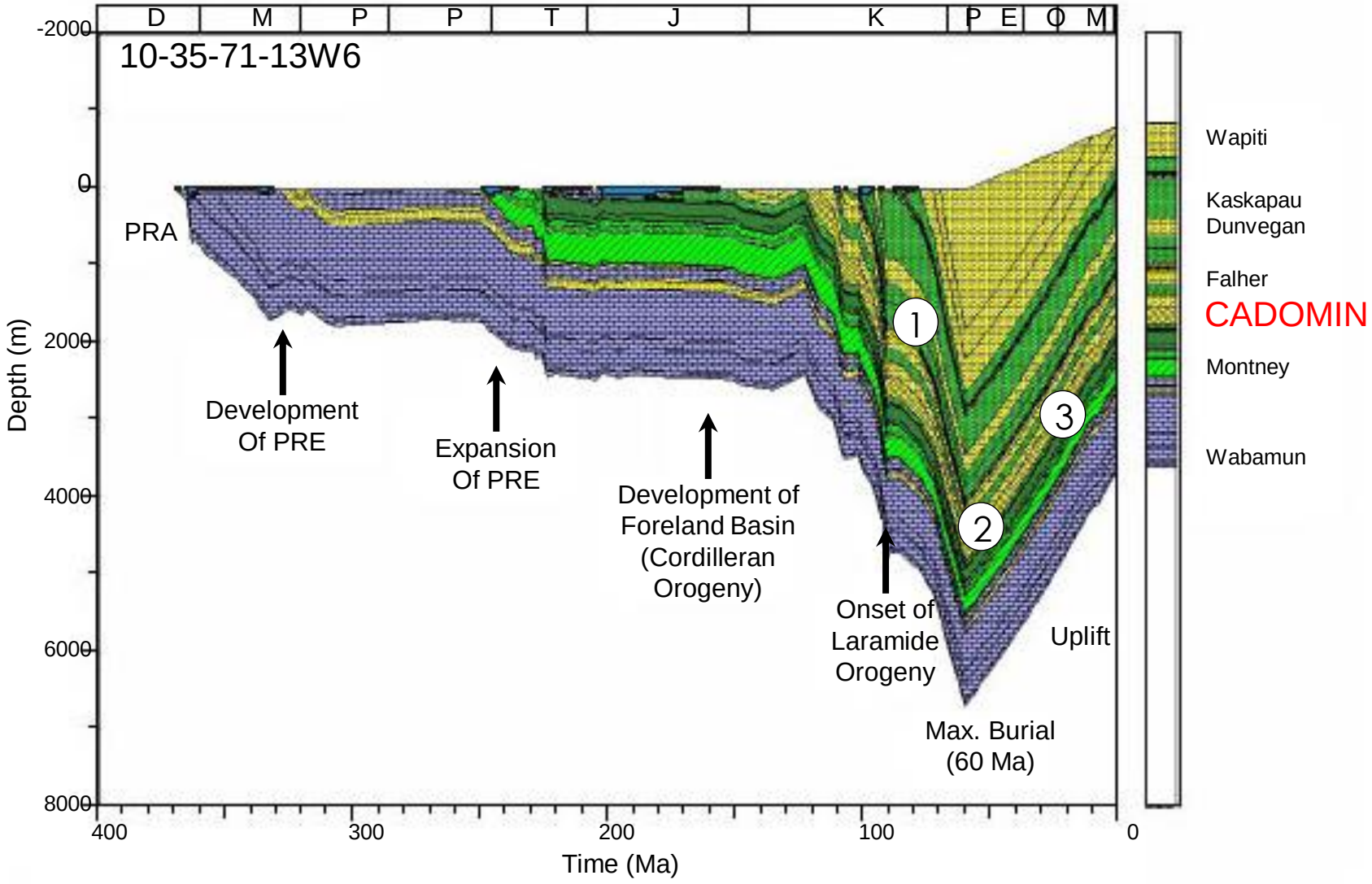
Controls on the Distribution of the Gas-Saturated Deep Basin Type Burial History Curve, WCSB



Shona M. Ness and Ian Hutcheon ASRG Website 2006

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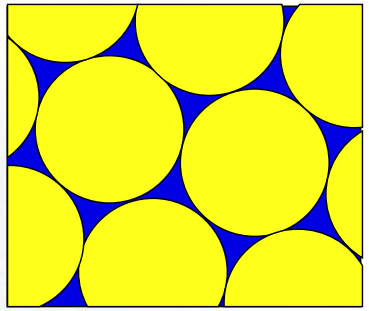
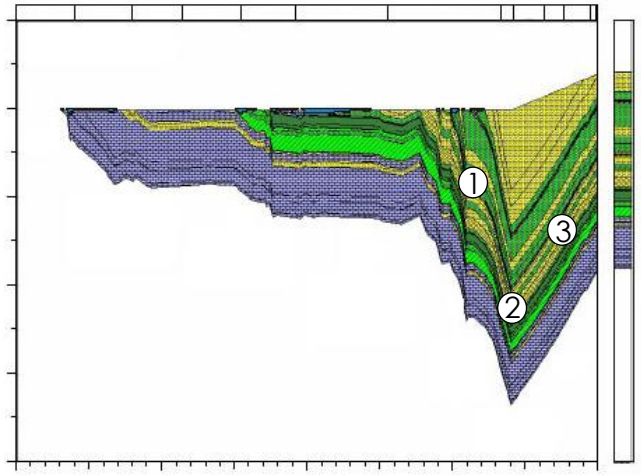
Slot K - Conceptual Grain Expansion and Contraction

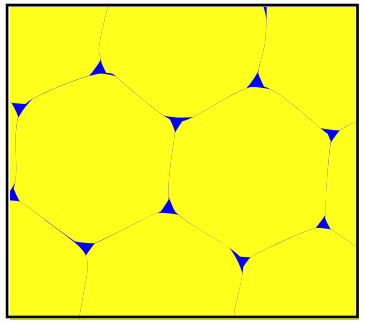
① At Deposition





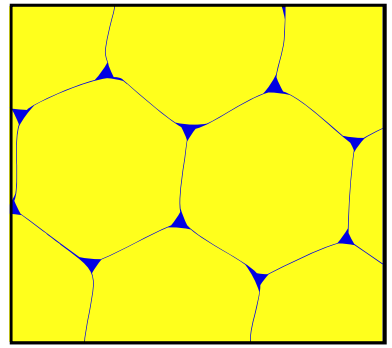
Open, Inter-connected pore system

② At Maximum Burial



Grain crushing, pressure solution isolate inter-granular pores

③ After Partial Uplift



Inter-granular pores again connected through grain bounding tabular pores

Billingsley et al., 2005

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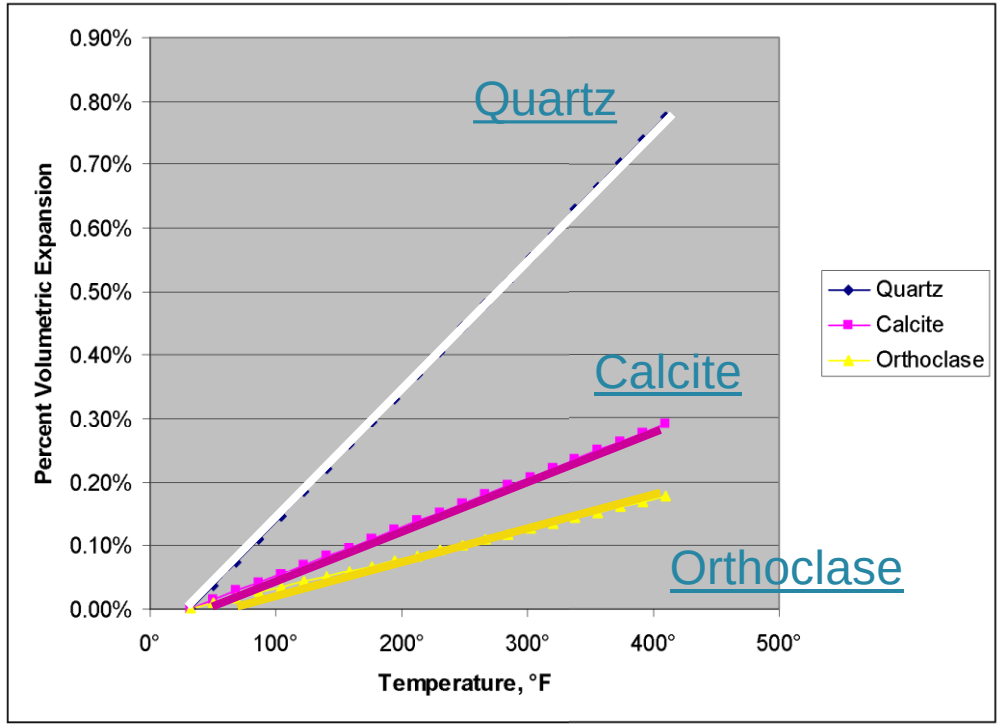
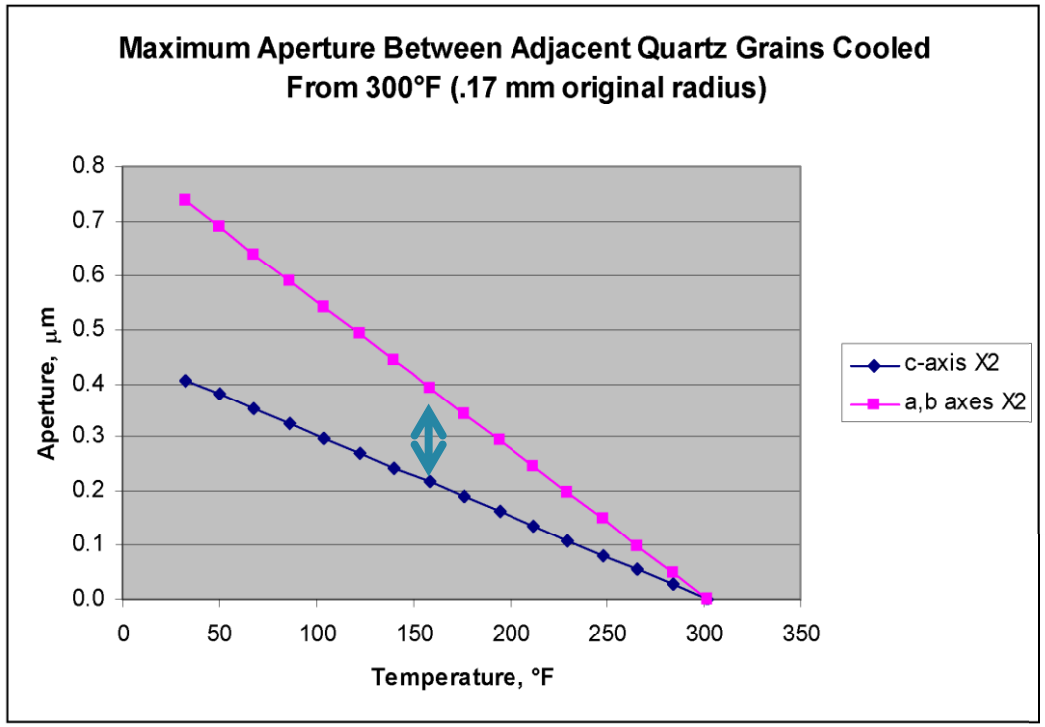
Thermo-elastic Expansion of Constituents



Thermo-elastic stress generated by grain expansion is a major (~40%) component of burial stress. Quartz is significantly more sensitive to temperature than other common constituents of the reservoirs.

Billingsley et al., 2005

Microfracture Apertures Generated by Thermo-elastic Contraction



Grain bounding apertures between 0.2 and 0.4µm would be expected to develop between adjacent 0.17µm quartz sand grains.

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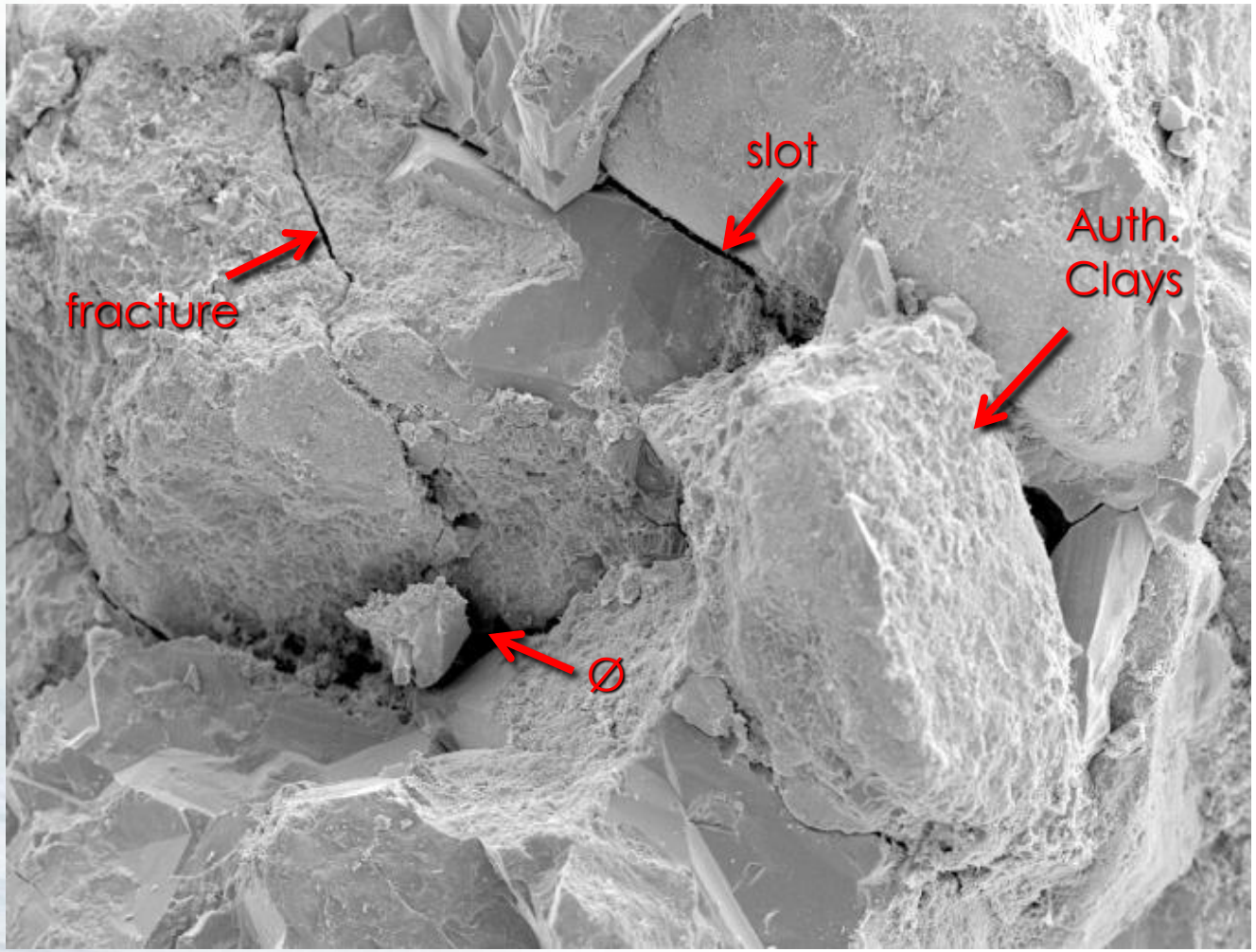
Nikanassin - Wapiti (15-27-66-10W6)



Porosity Styles:

- Primary Ø
- Leached Ø
- Fracture Ø
- Slot Permeability / Ø

Zaitlin and Moslow, 2005

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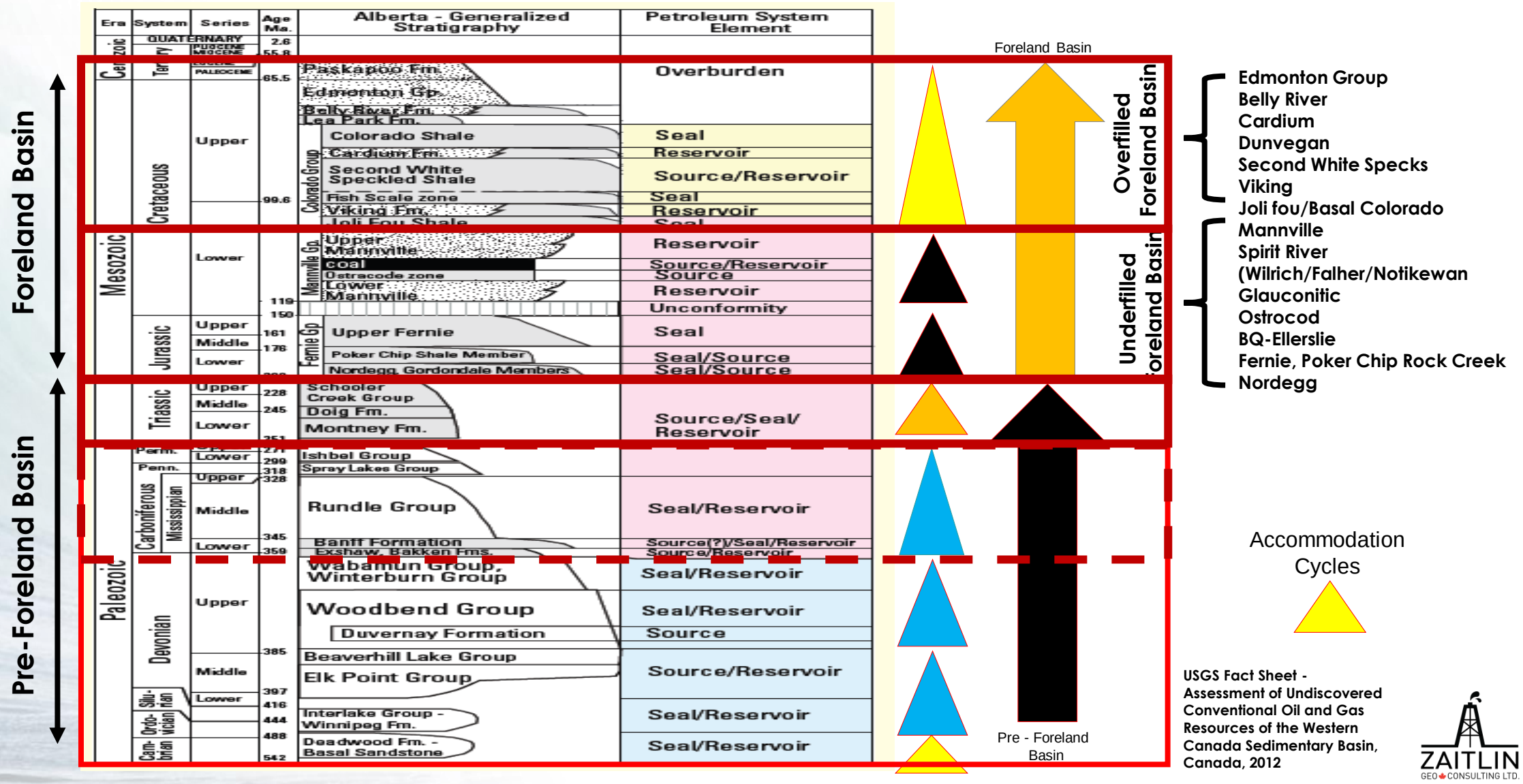
Western Canada Sedimentary Basin (WCSB)



USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012

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Depositional Styles
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Underfilled FB vs. Overfilled FB

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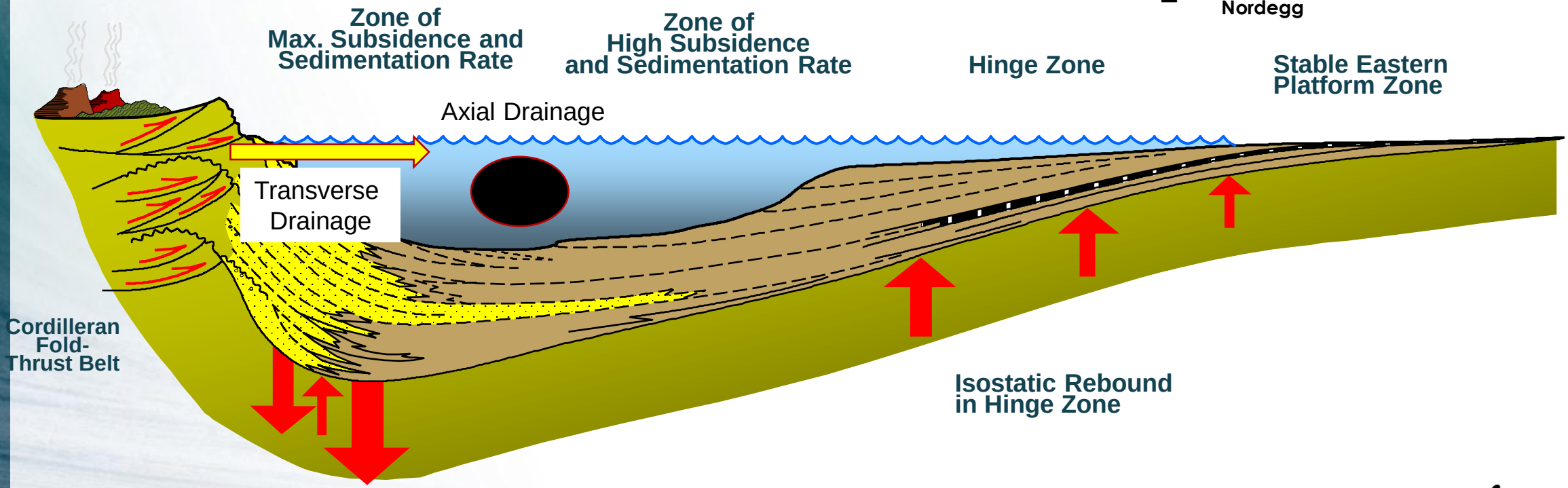

modified after Kauffman, 1984

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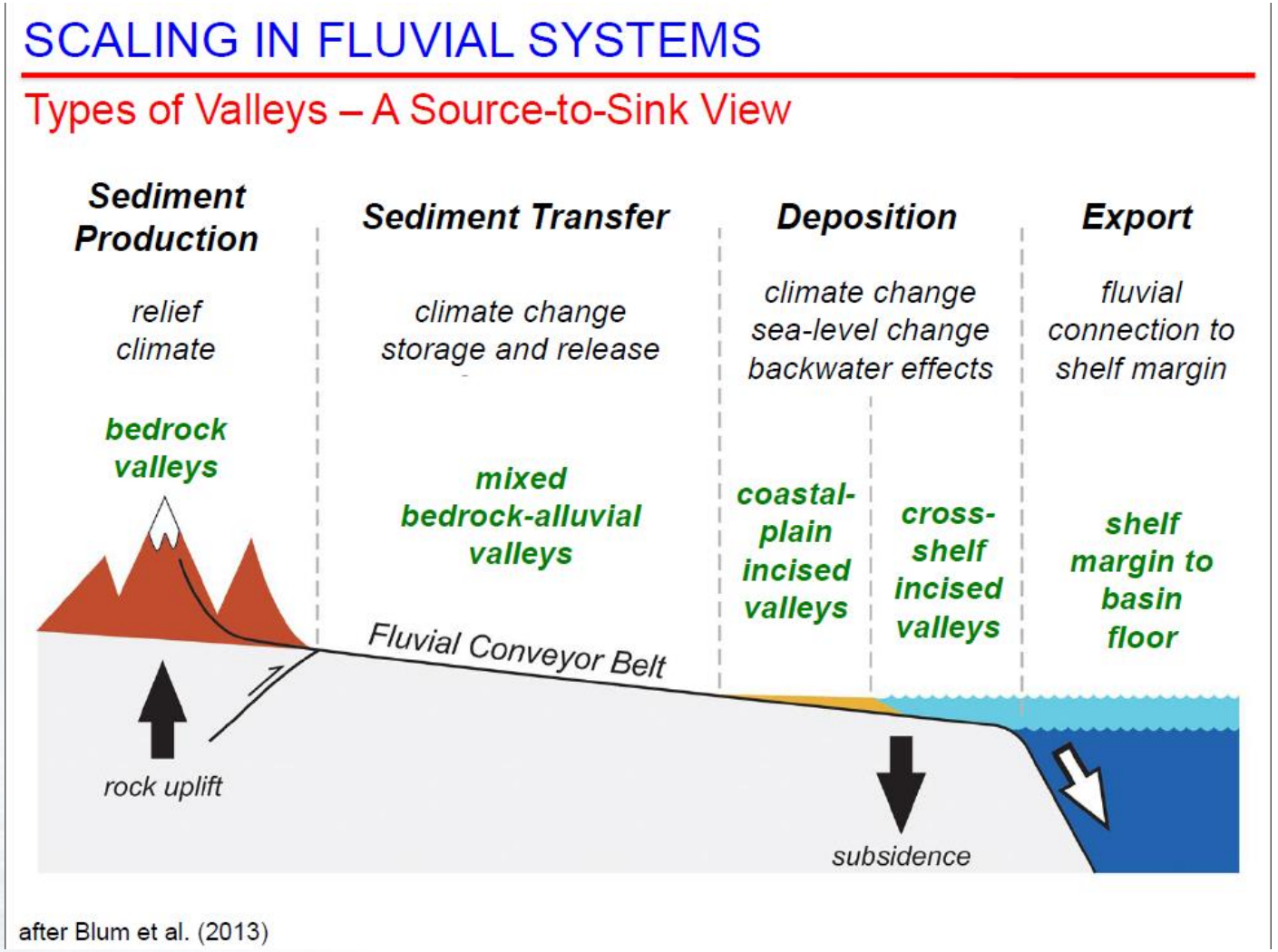
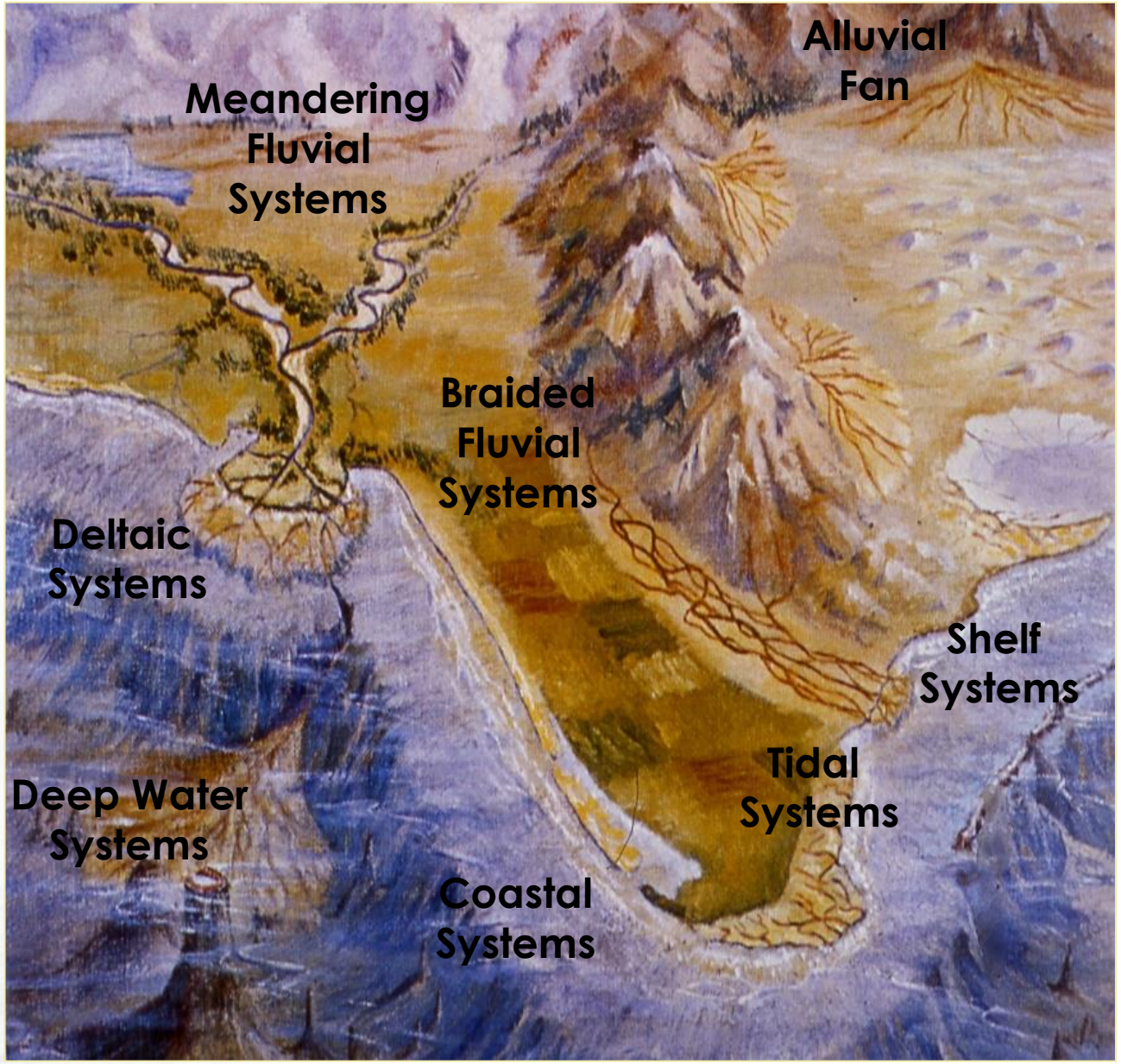
Source to Sink Concept
Applied to the WCSB Foreland Basin
Incised Valley Systems – Shoreline Orientation



Depositional Systems



SEPM Special Publication Cover

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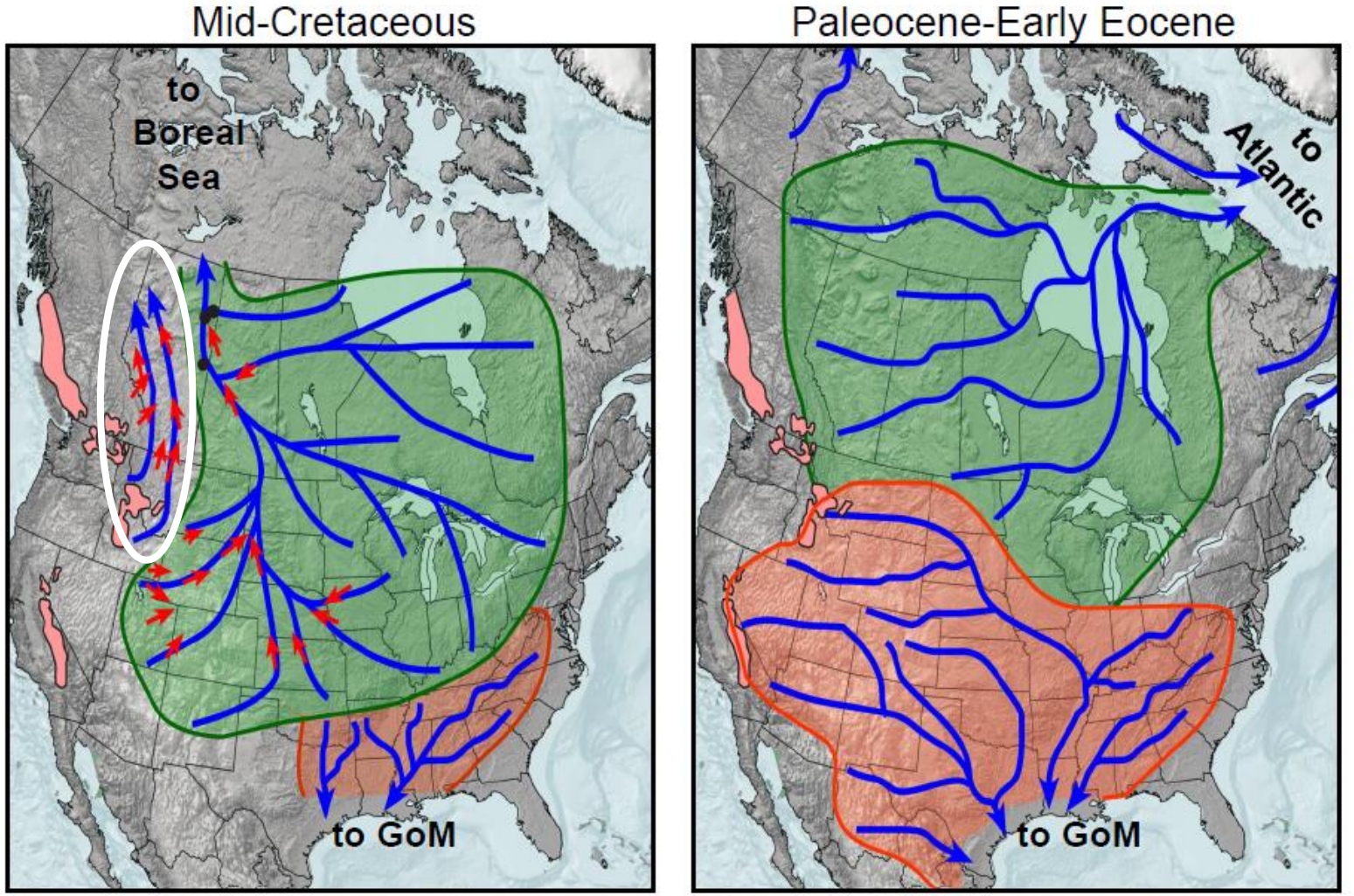
Continental Scale Paleodrainage Reorganization

Underfilled Foreland Basin Drainage to north



Blum et al., 2015

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Foreland Basin
Axial Drainage vs. Transverse Drainage
Underfilled FB

Underfilled Foreland Basin

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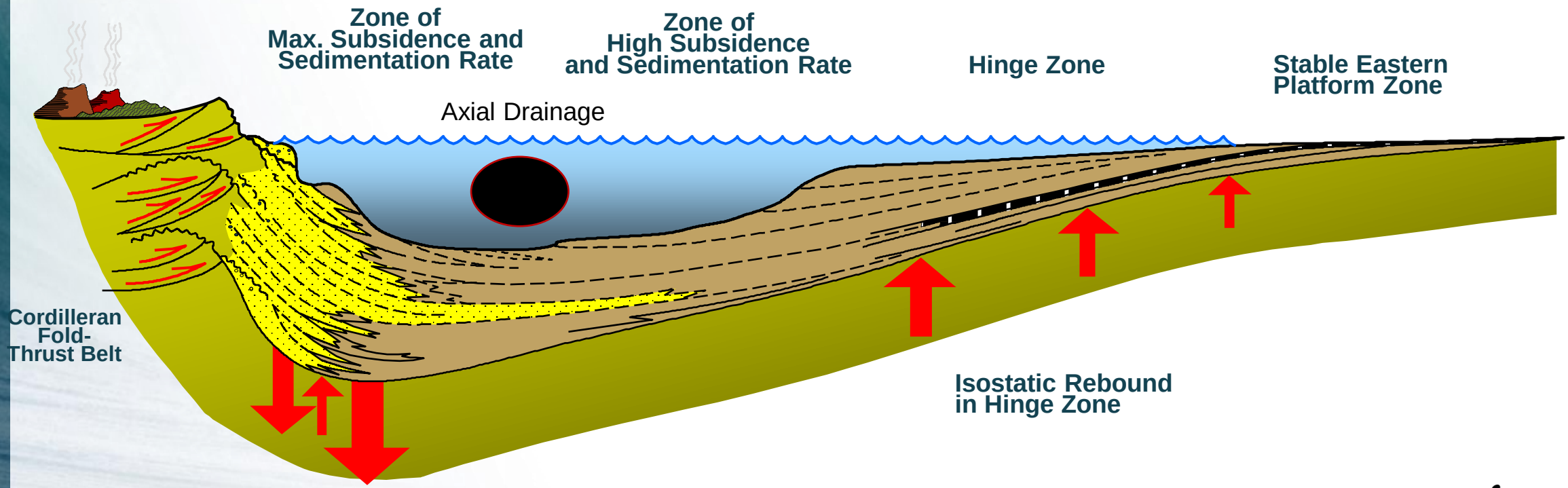

modified after Kauffman, 1984

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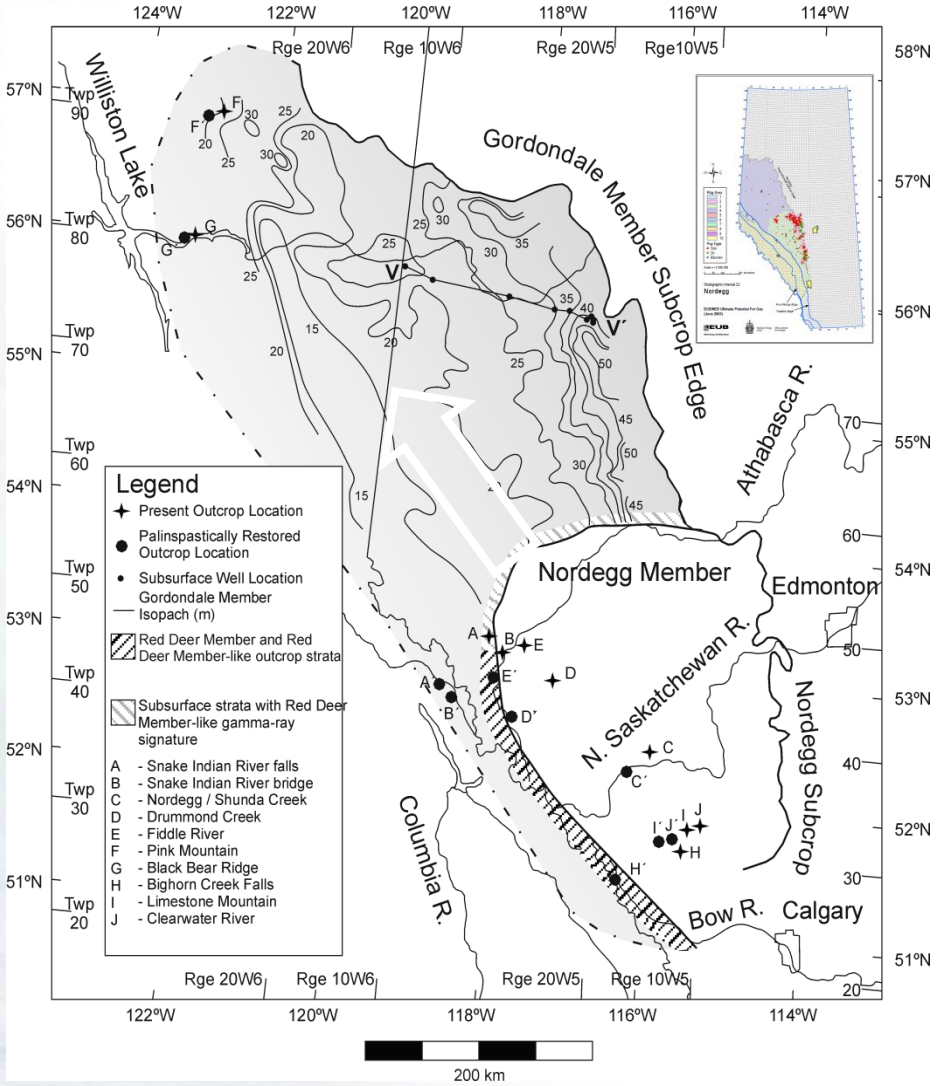
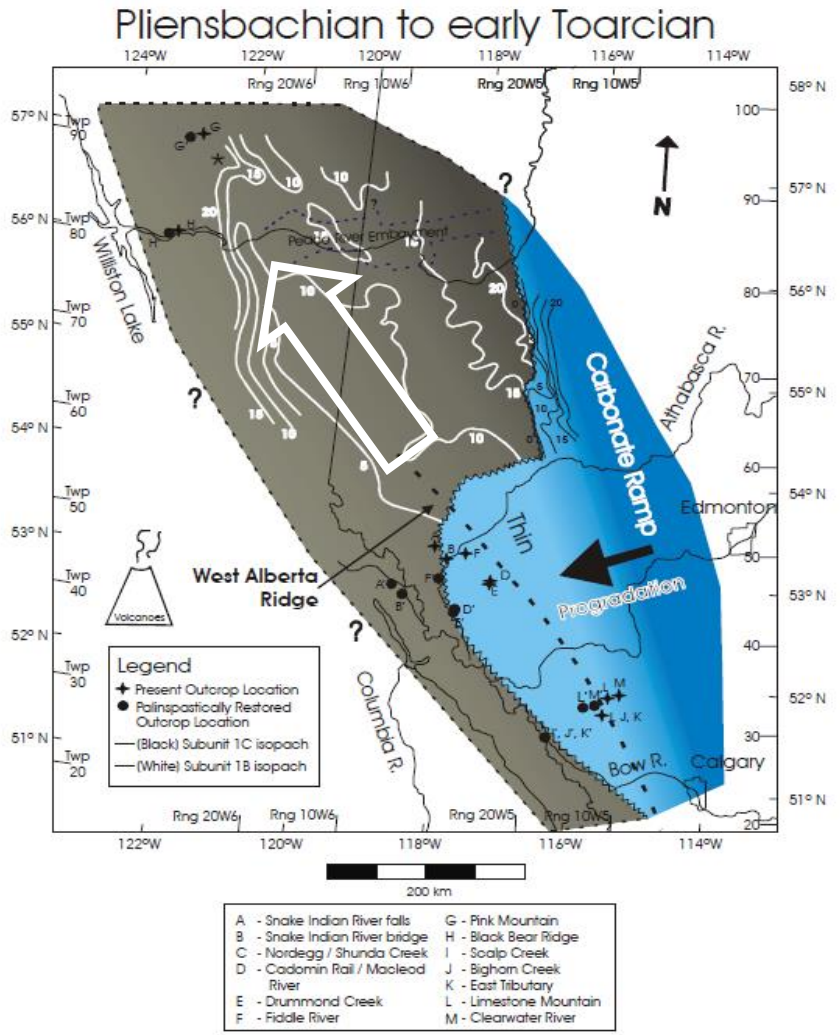
Jurassic Nordegg FM - Foreland Basin





Axial Paleodrainage

Asger – Deen Ph.D. Thesis

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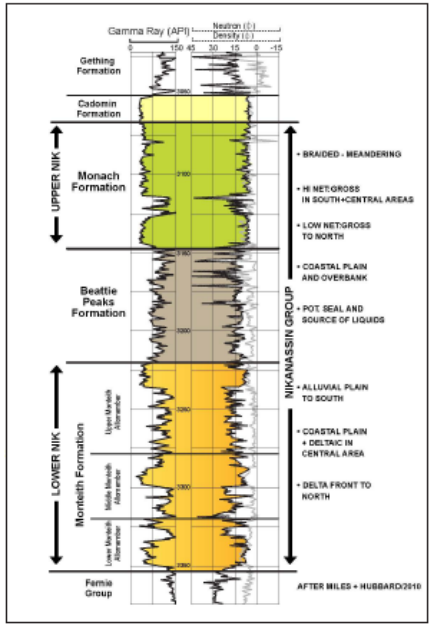
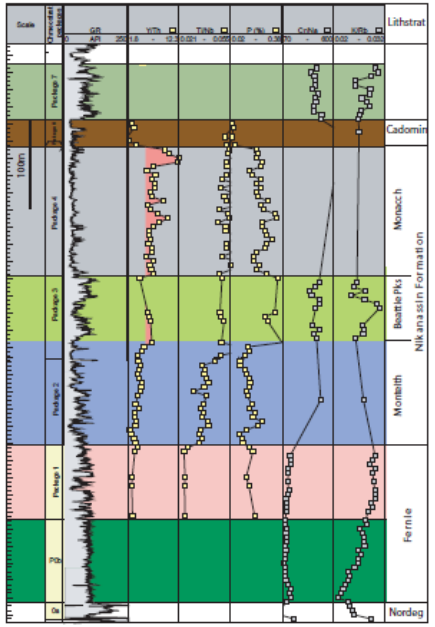
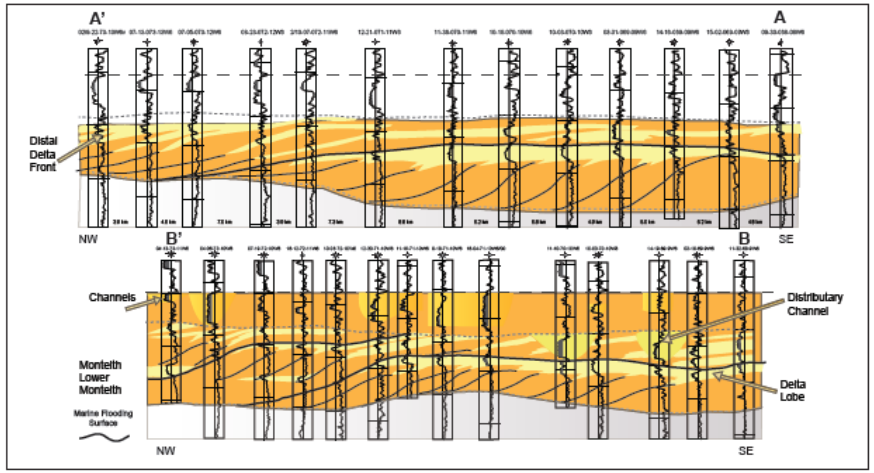
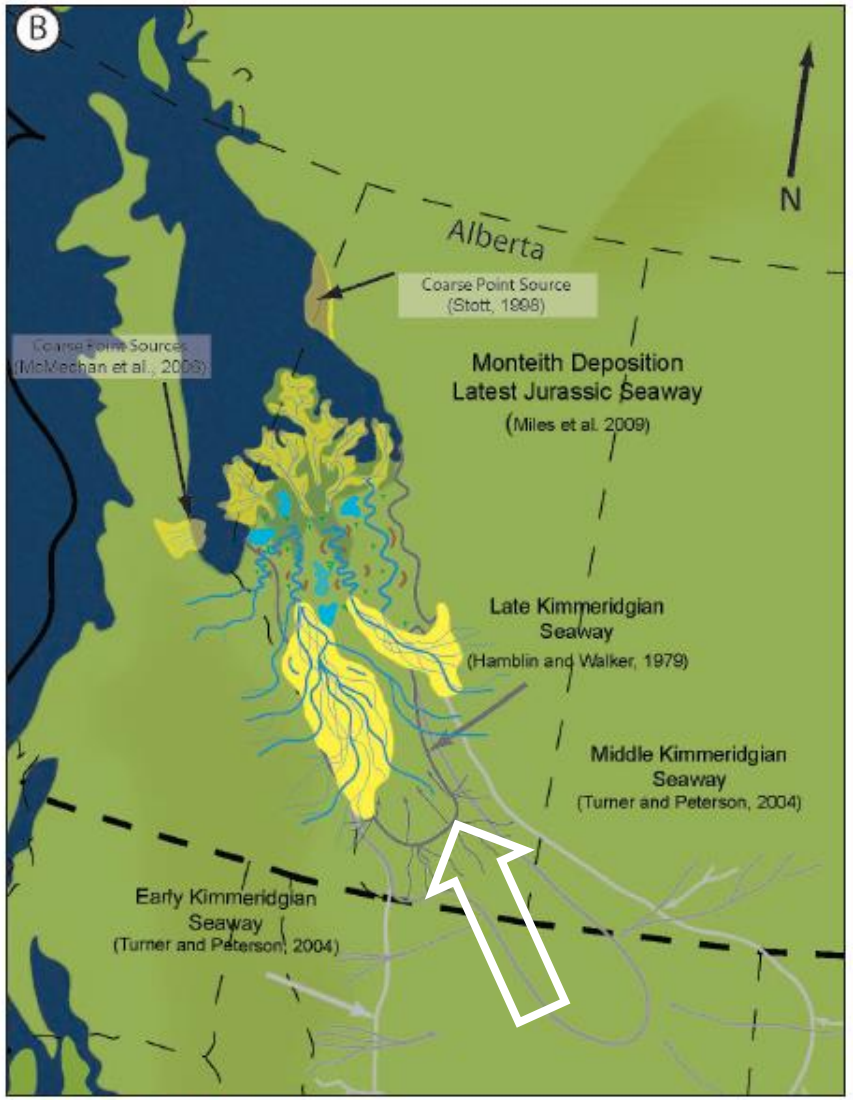
Jurassic Nikinassin Fm







Source: after Miles and Hubbard, 2010



Source: after Miles and Hubbard, 2010

Axial Paleodrainage

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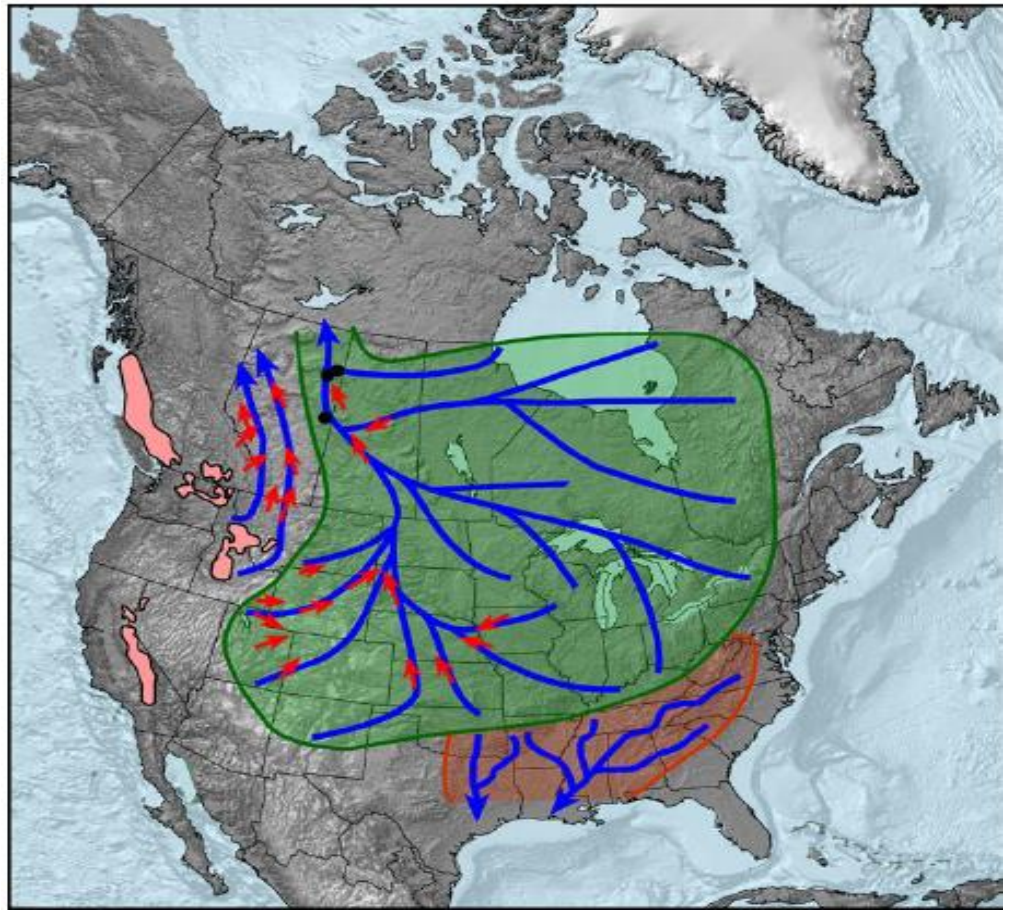
Lower Cretaceous – Aptian (120-115 Ma) (Cadomin, Gething, Basal Quartz)

Ron Blakey, 2013



Blum, 2015

Paleodrainage

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Criteria for the recognition of Incised Valley Systems

1- Truncation

2- Downward Shift

3- On lap

4- Regional Extent

5- *Tributary Junction Scours (TJS)*

Issue – Distinguishing between Marine Shales and shoreface deposits of Jurassic age from L. Cretaceous Incised Valley Deposits

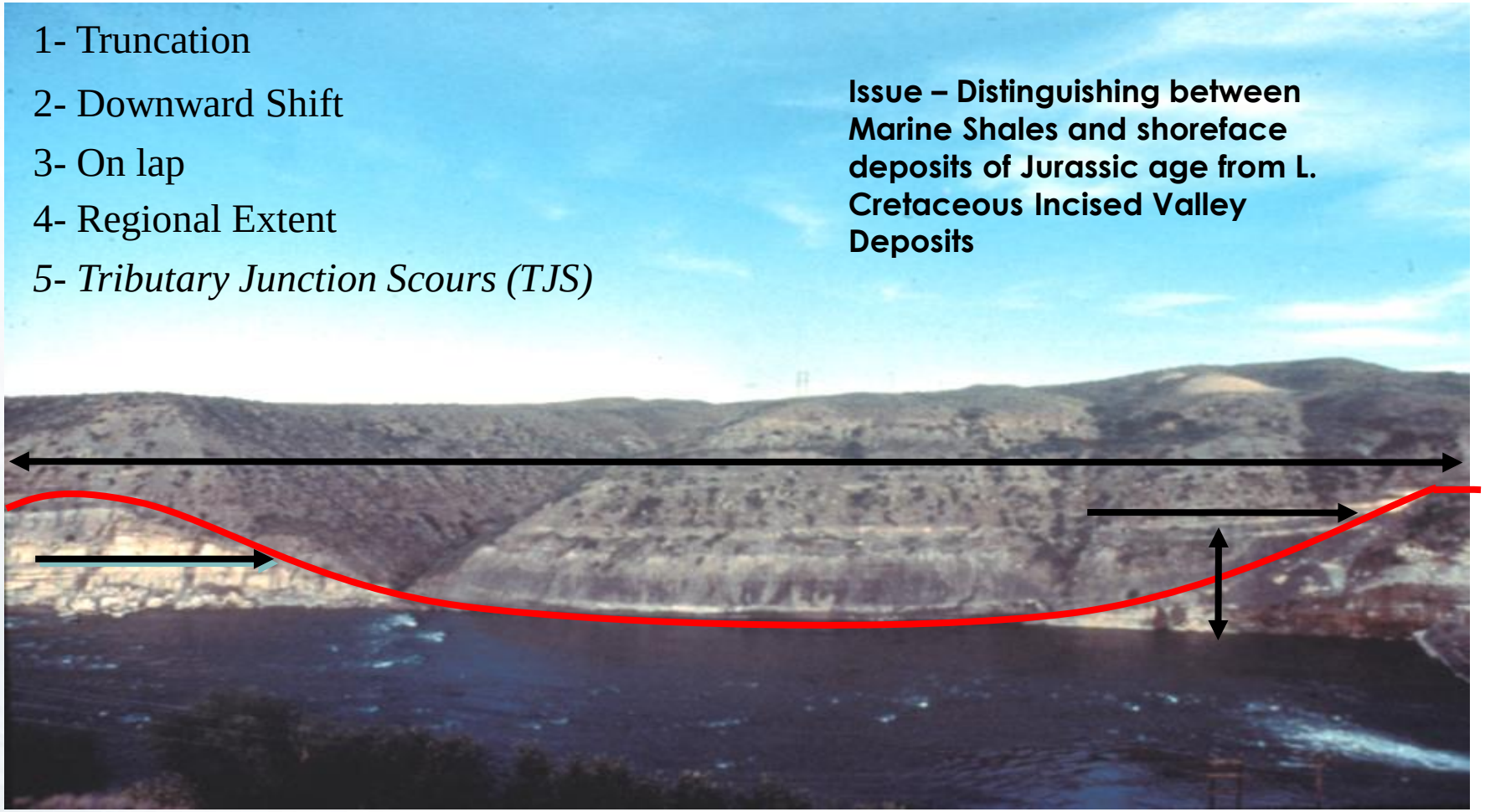

Photo Courtesy of P. Putnam

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Criteria for the recognition of Incised Valley Systems: Tributaries and TJS

New South Wales Coast

Milk River

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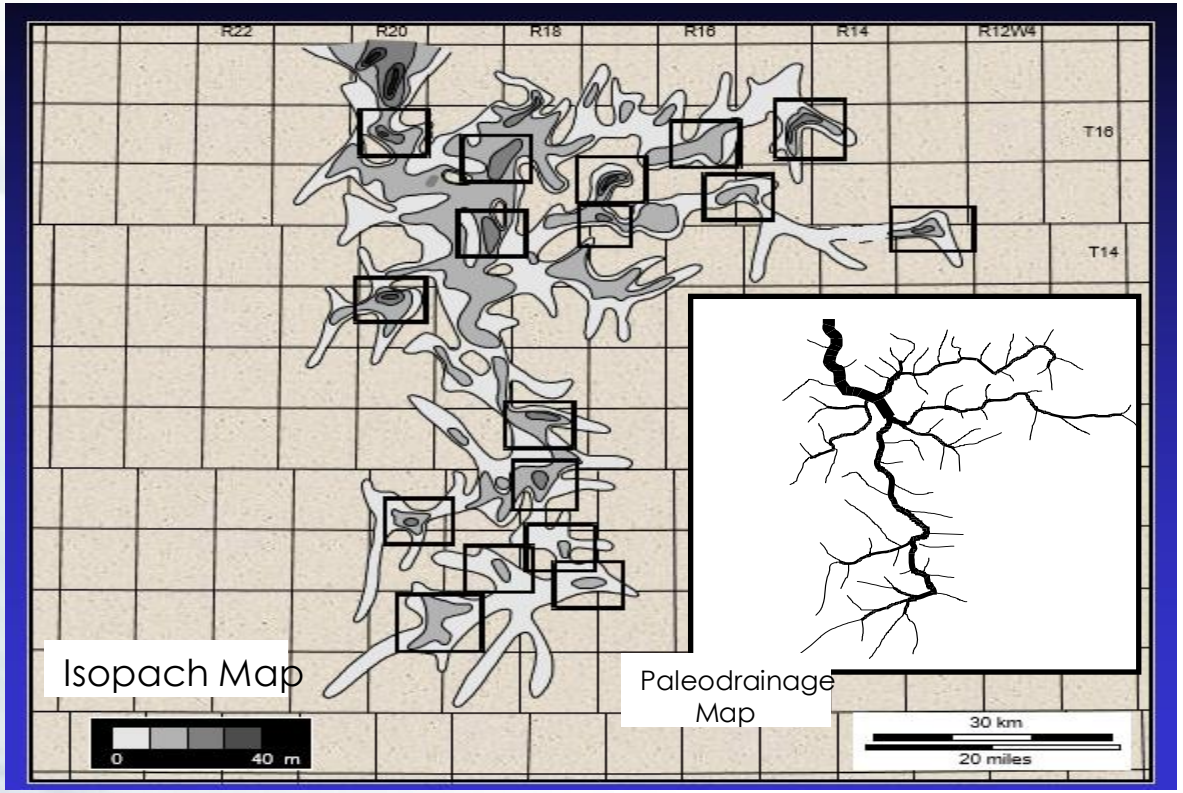
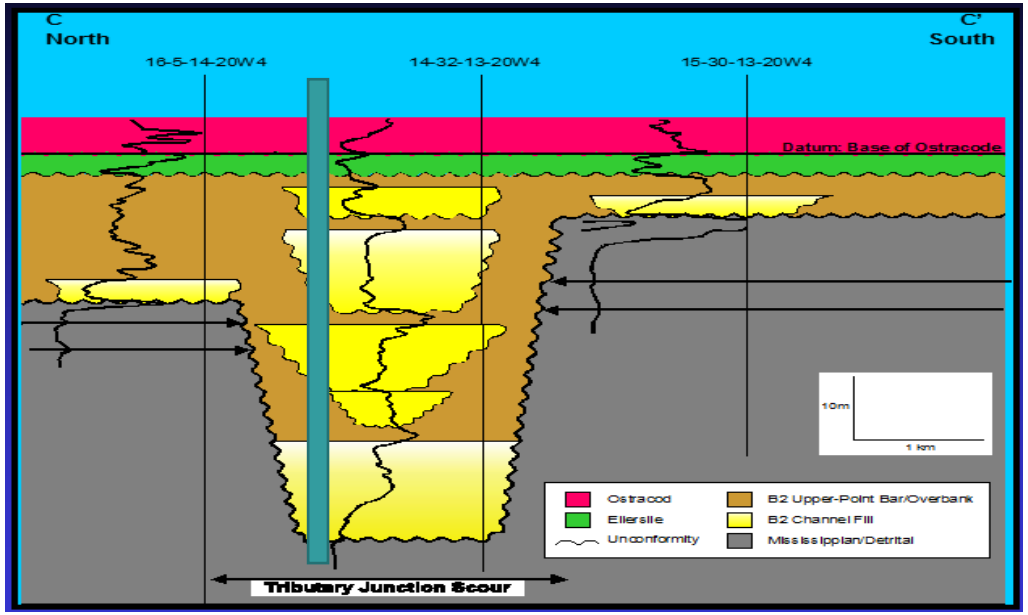
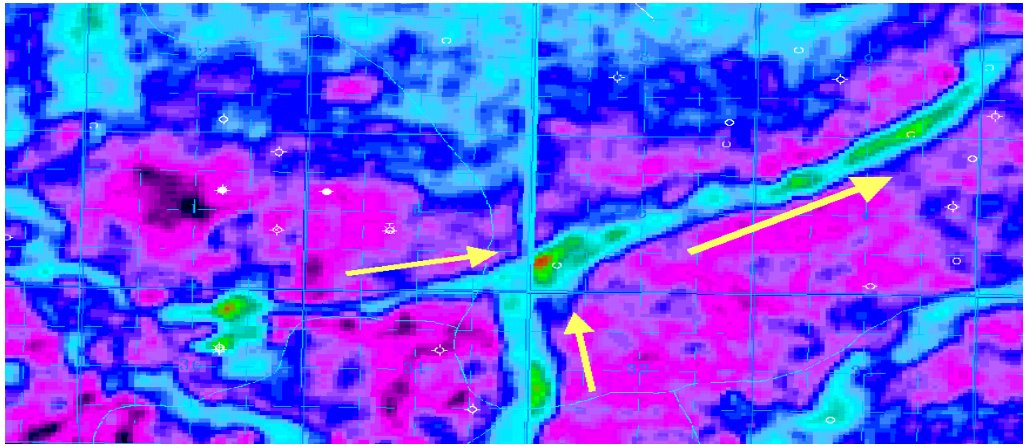
Tributary Junction Scours
Analogue for the 100/16-34-049-13W5/00
Compound Ellerslie IV Facies (IV 2)







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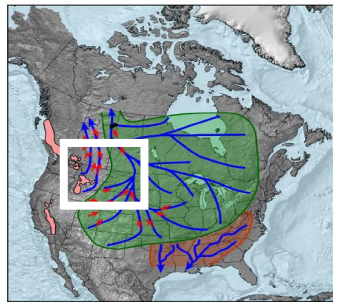
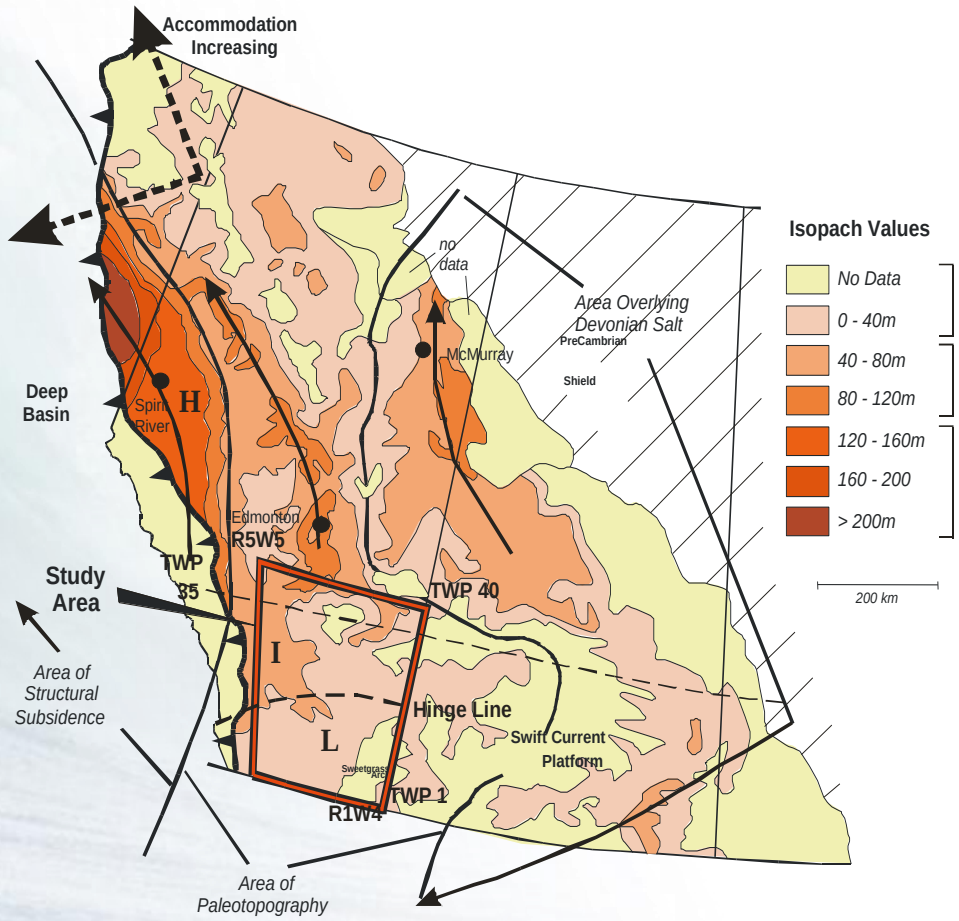
Lower Cretaceous
Aptian (120-115 Ma)

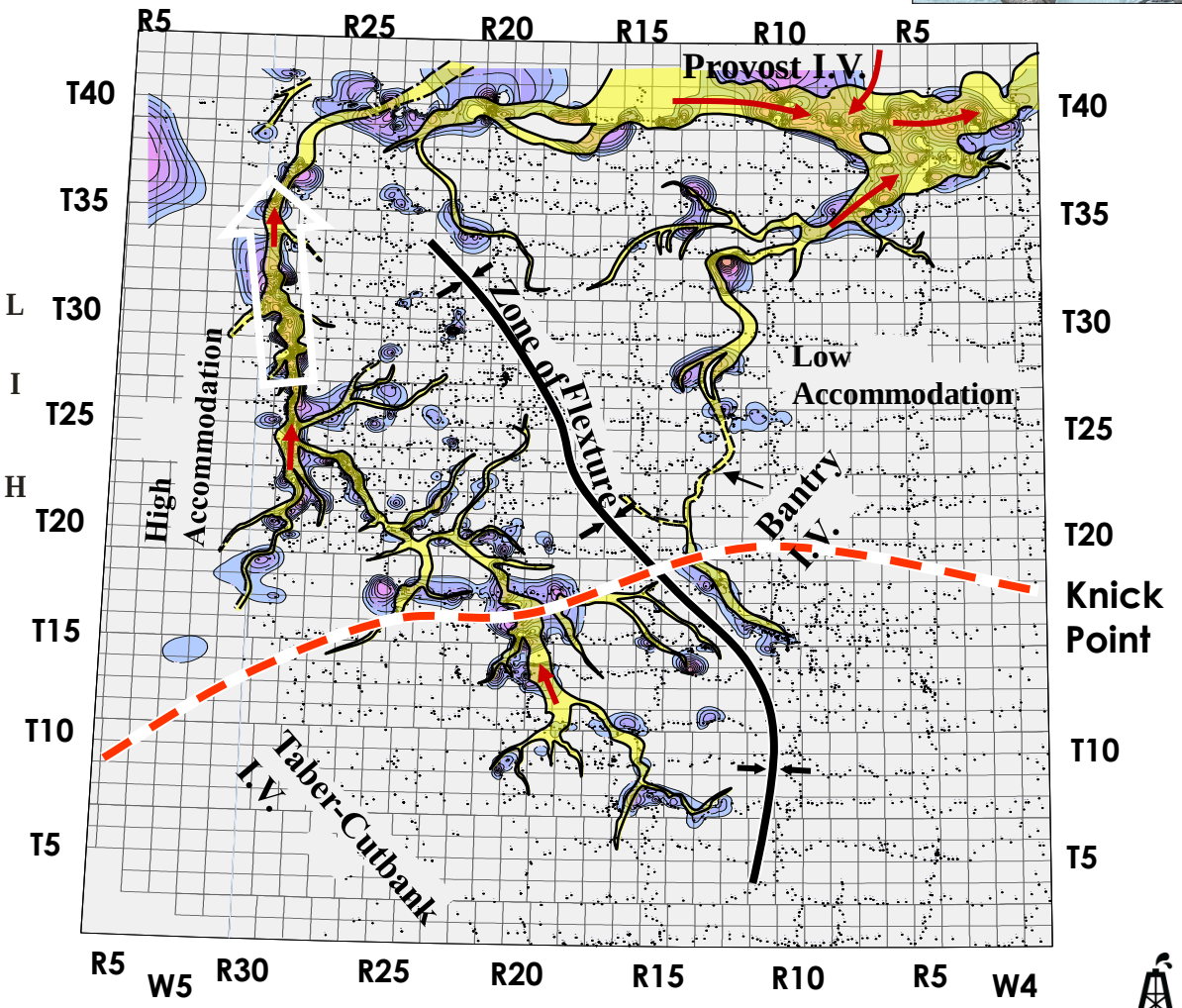


Isopach Map
Jurassic to Ostrocod and equivalents



modified from Cant and Abramson; Zaitlin et al, 2002

Isopach Map – "BAT" Cycle 2



Zaitlin et al, 2002

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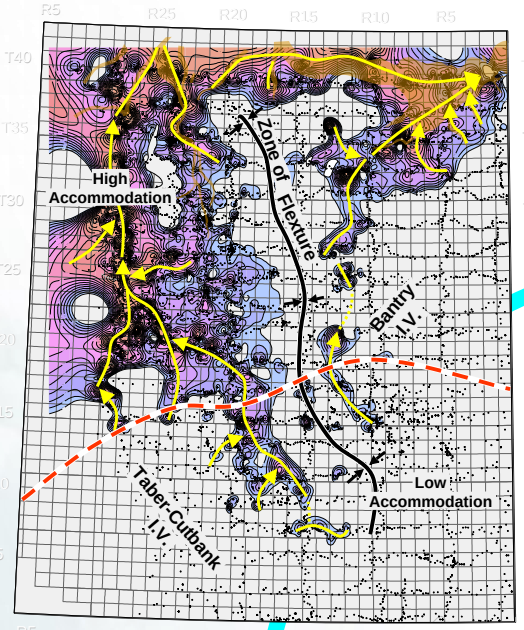
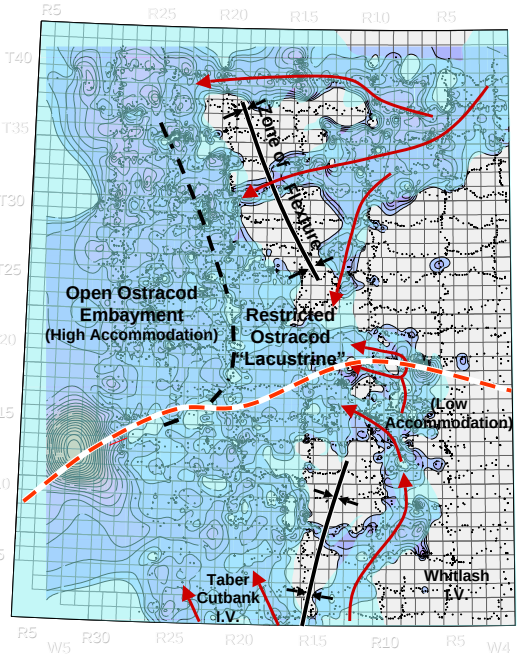
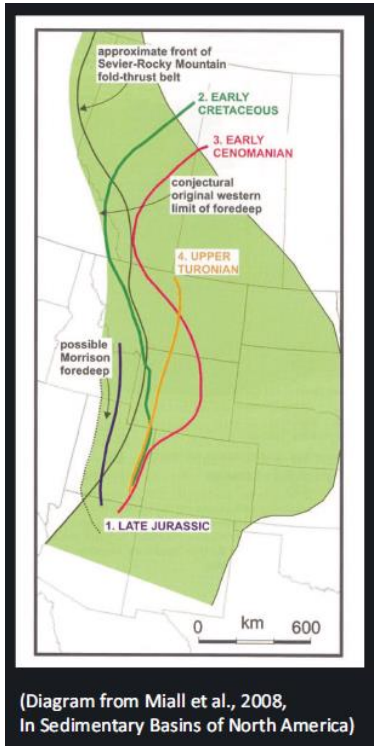


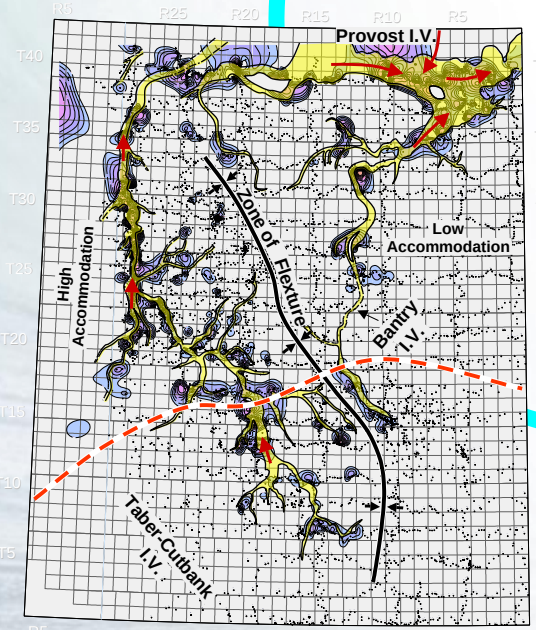
Cycle 2 Paleogeography Ellerslie Sandstone



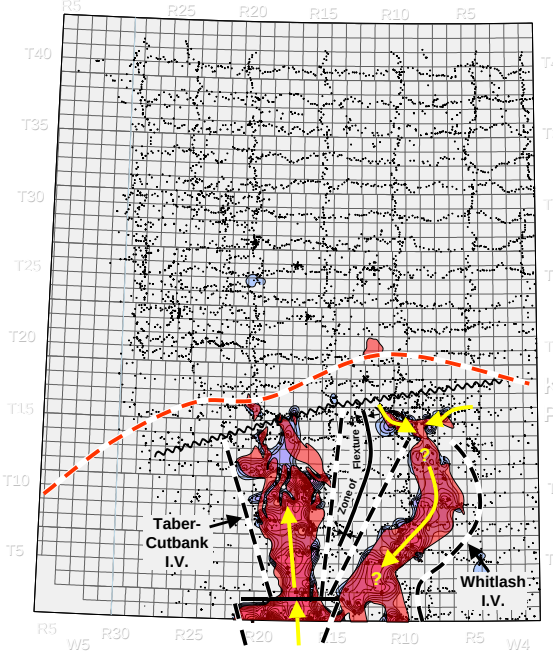
Cycle 2 Paleogeography Ostracod



(Diagram from Miall et al., 2008, In Sedimentary Basins of North America)



Cycle 2 Paleogeography "BAT" Sandstone



Cycle 2 Paleogeography Horsefly Sandstone

Zaitlin et al., 2002

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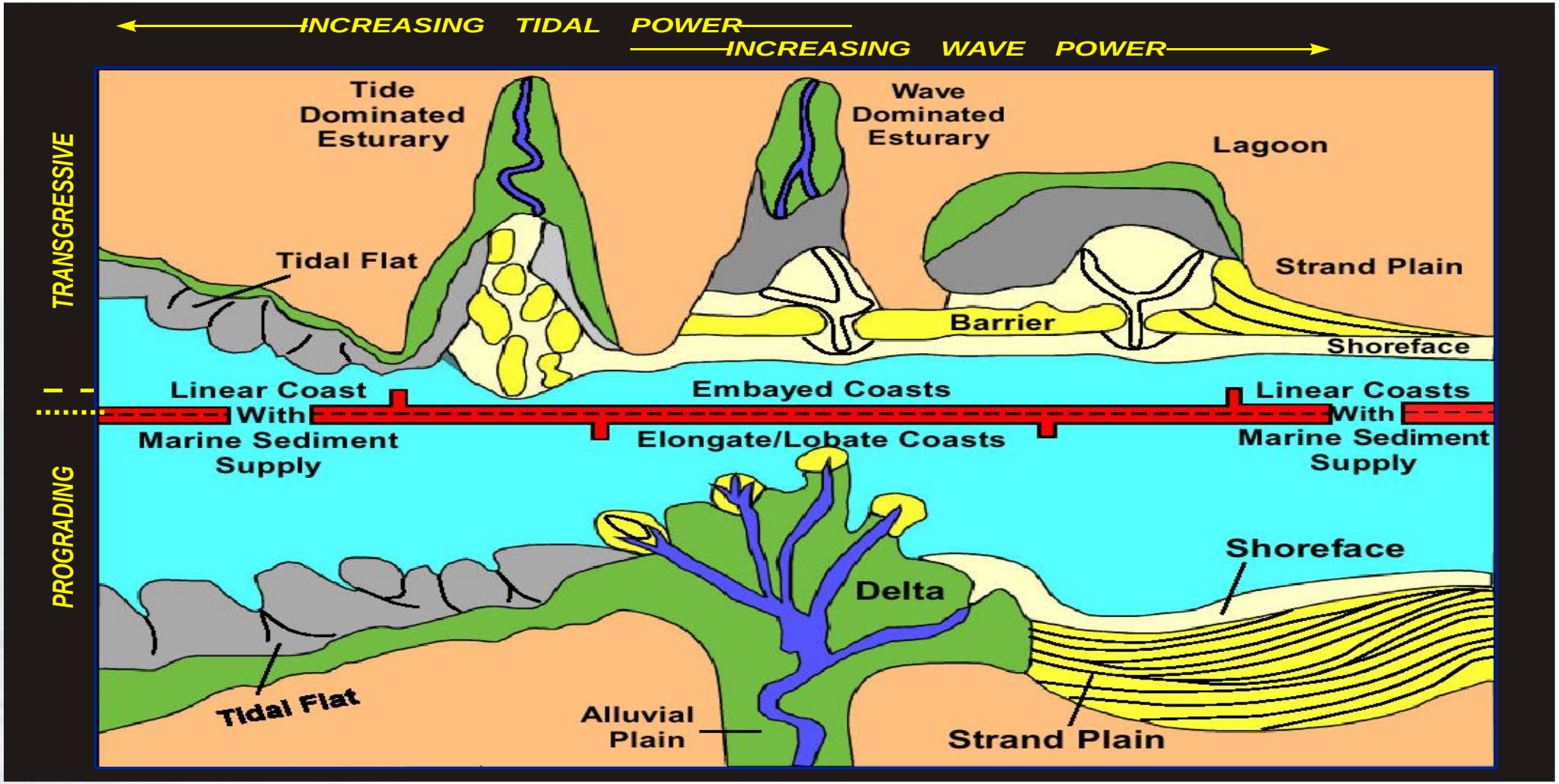
Coastal Classification – *along strike variation*



Boyd, Dalrymple and Zaitlin, 1992

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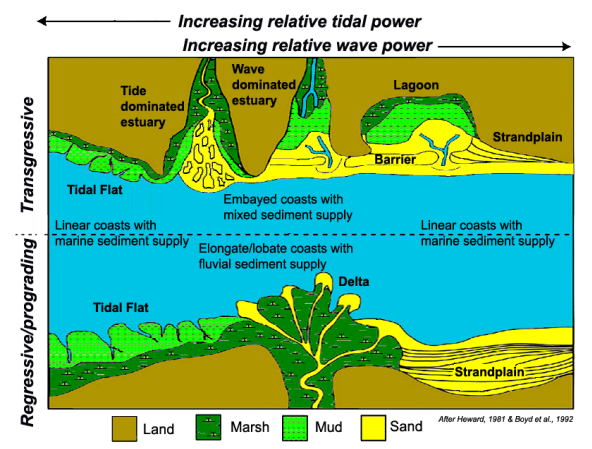
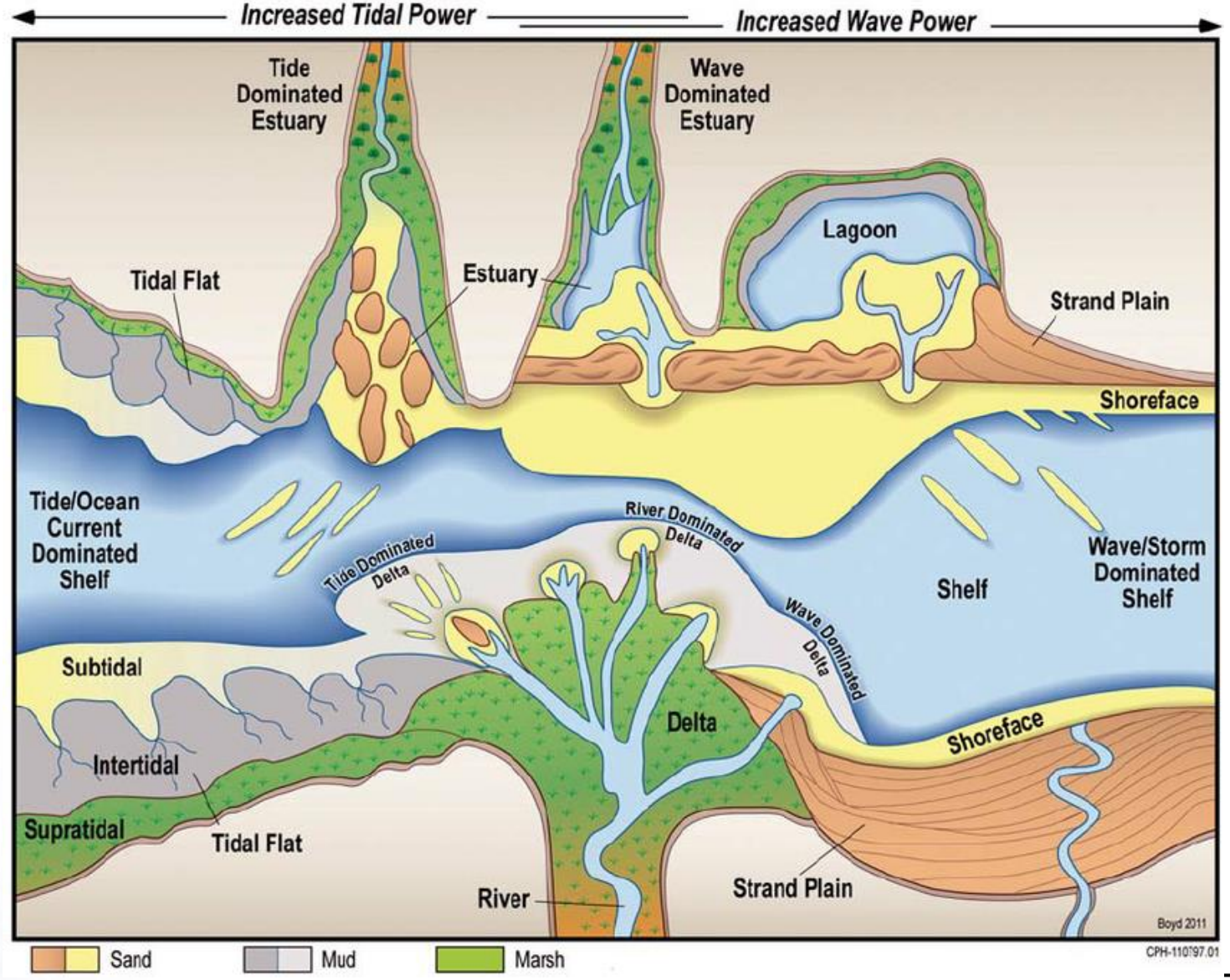
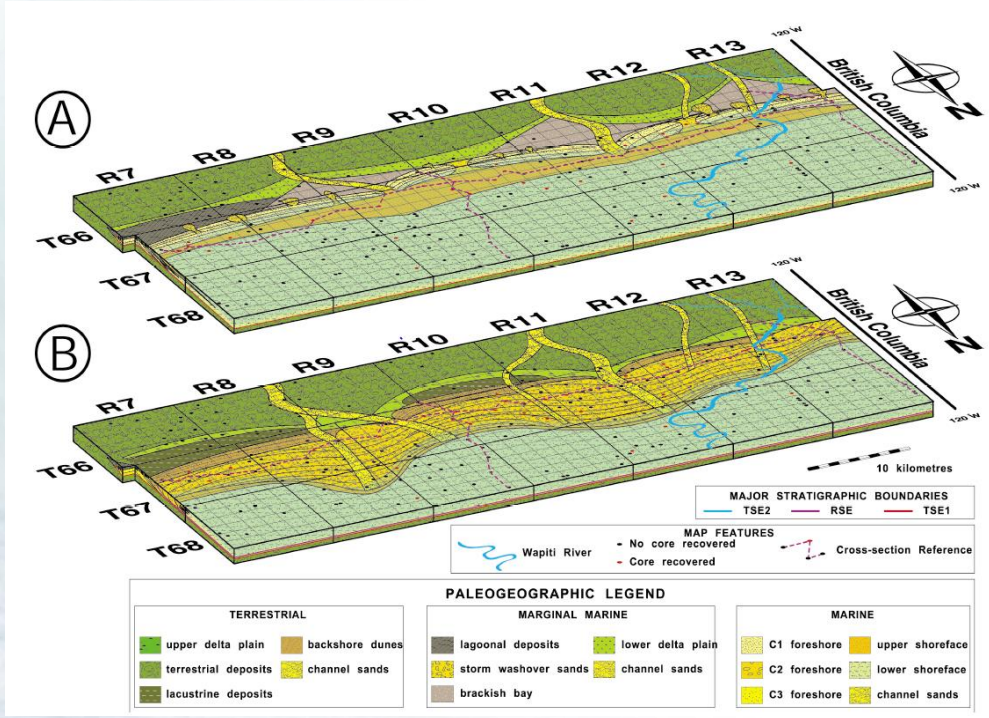
Shallow Water Depositional Systems

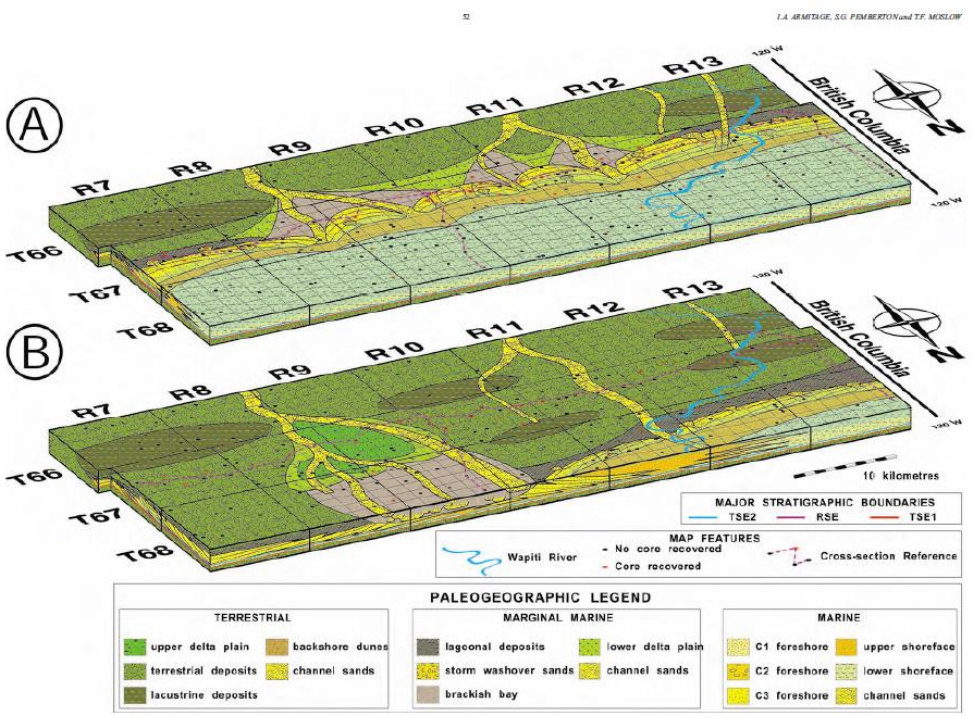


Boyd, Dalrymple and Zaitlin, 1992



Shoreline Depositional Model of along strike variation for a wave dominated shoreline, deltas and associated facies





(modified after Armitage, Pemberton and Moslow, 2004 for the Falher C)

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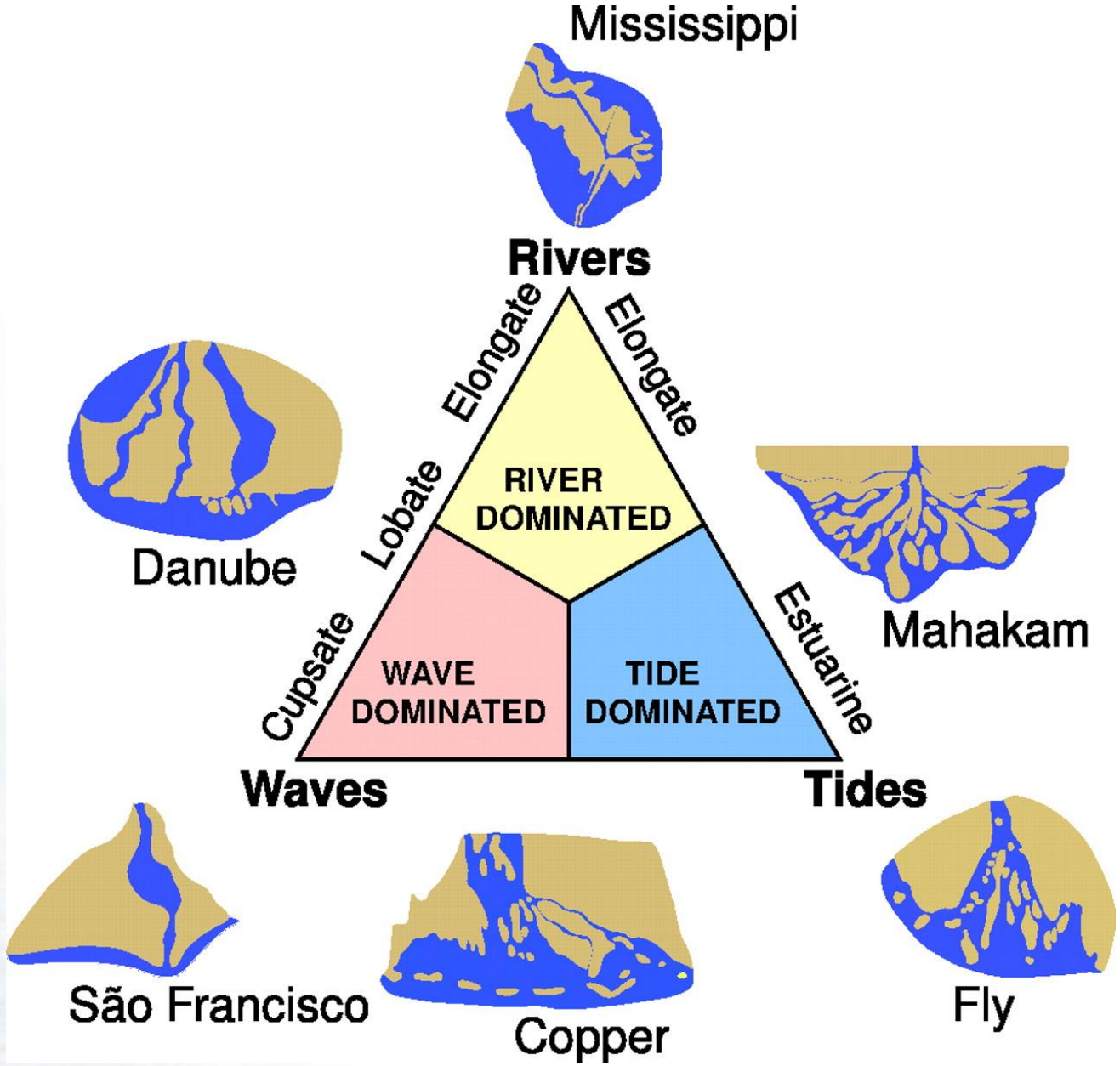
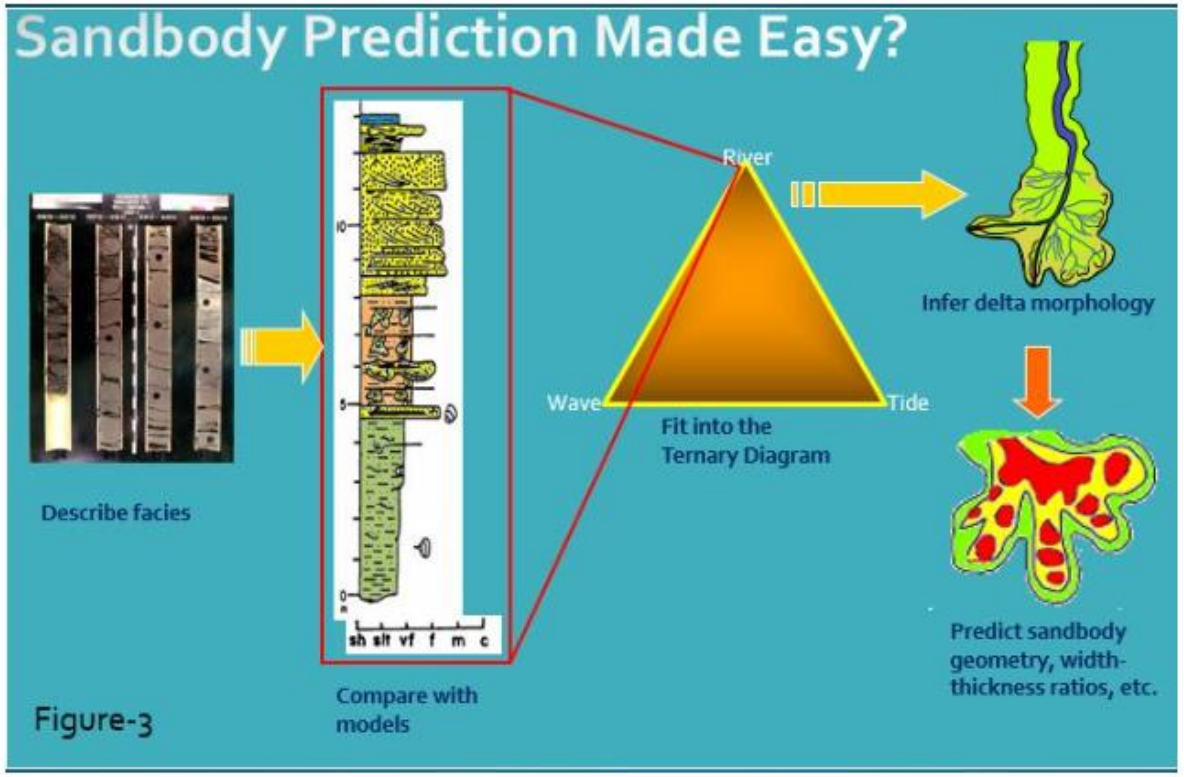
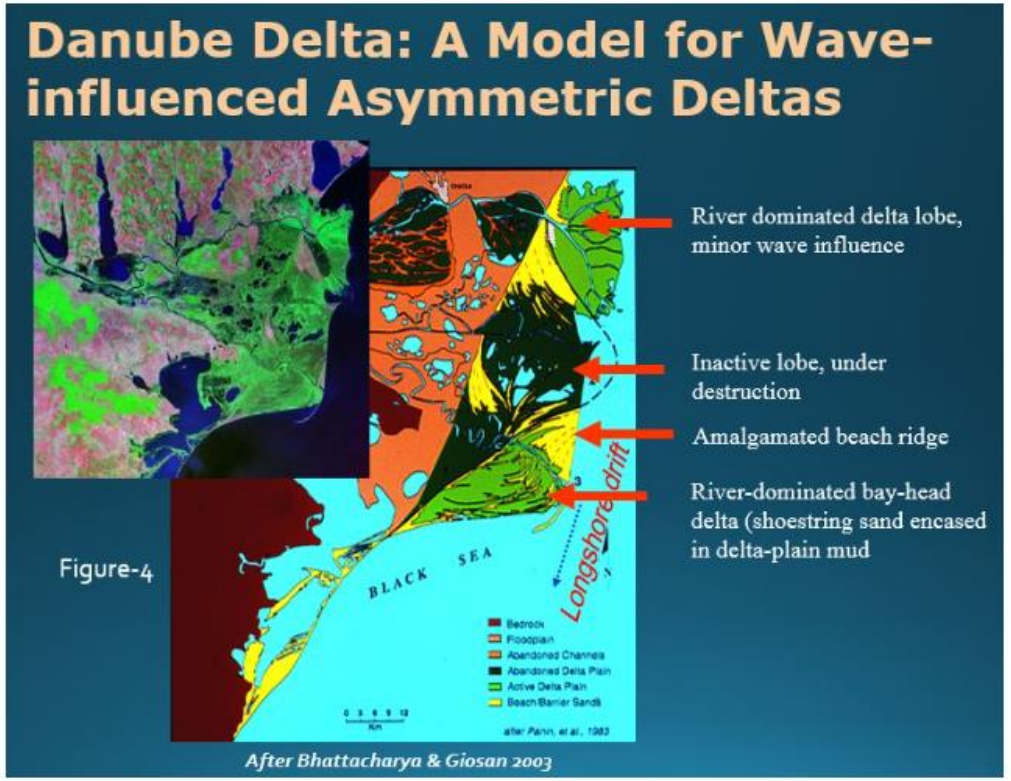
Delta Classification



Asymmetric Wave-Influenced Delta





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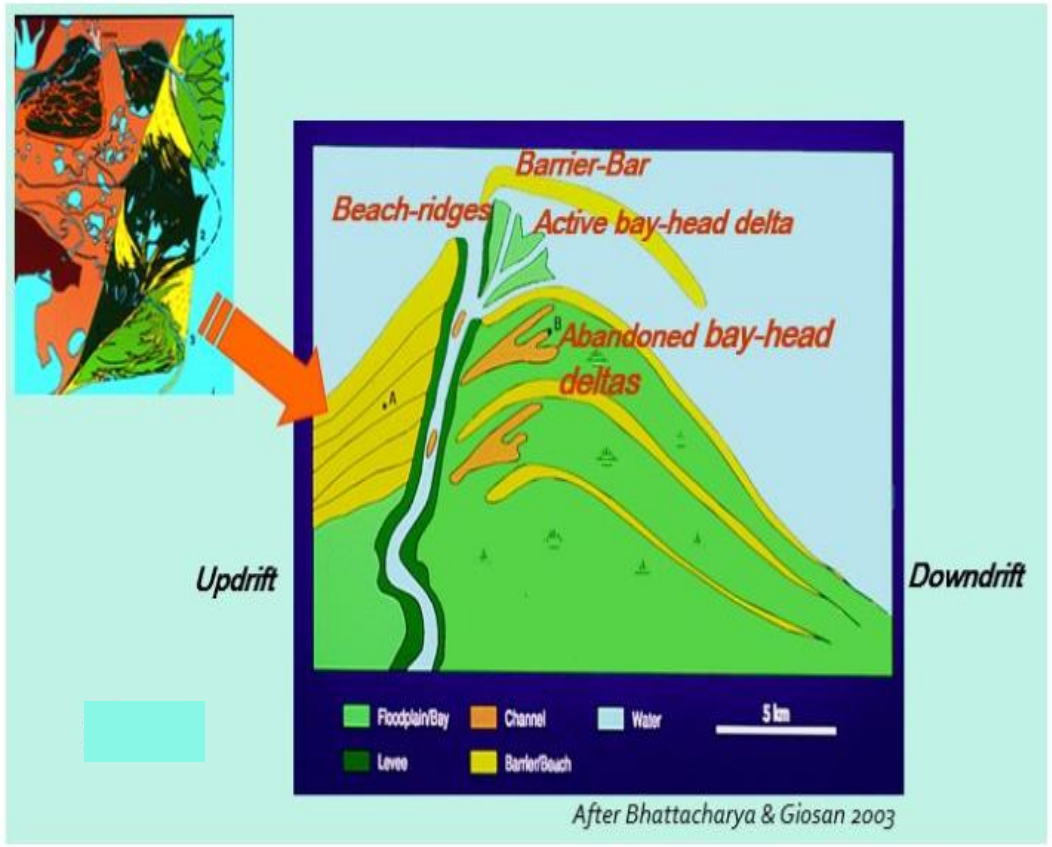
Asymmetric Wave-Influenced Delta



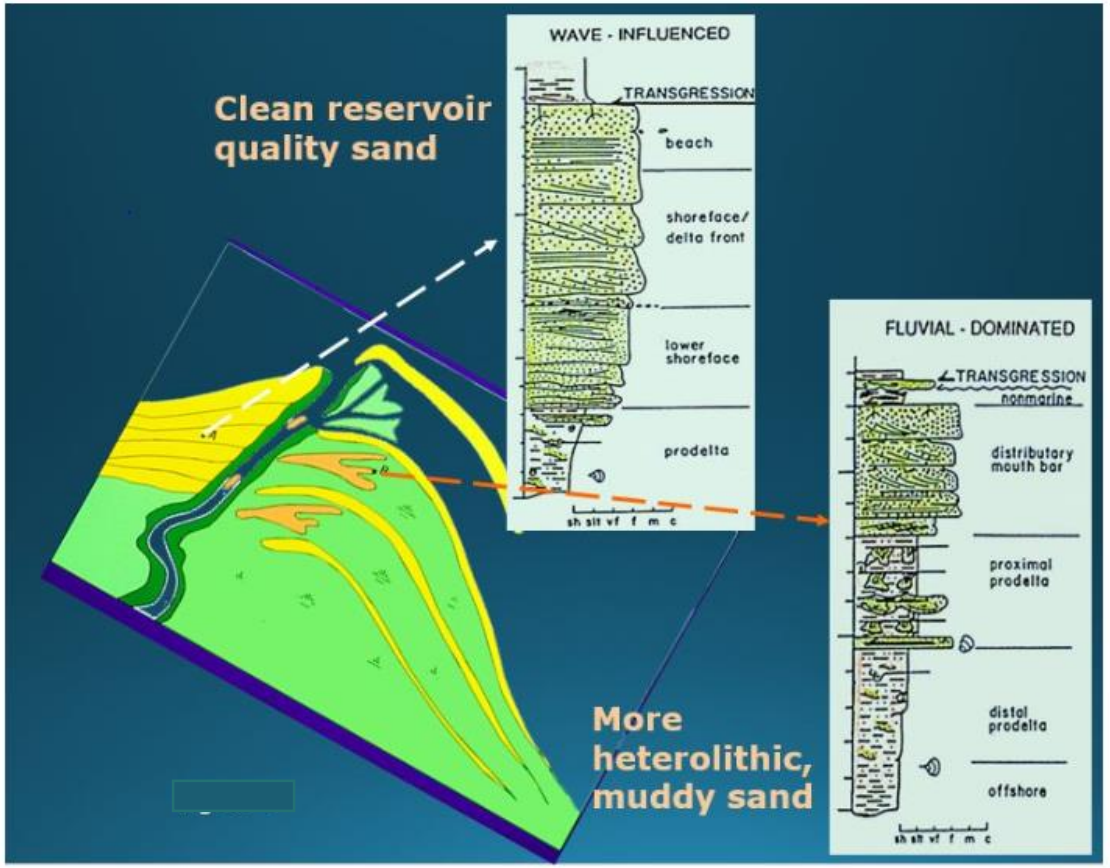
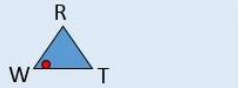


Figure-7

Updrift *: wave-dominated*

Downdrift *: river- and/or tide-dominated*



Junaid Sadeque, March, 2016

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Shoreface Profiles

Intermediate Shoreline Profile
Belly River, Dunvegan

Reflective Shoreline Profile
Falher, Viking Conglomeratic Shoreface

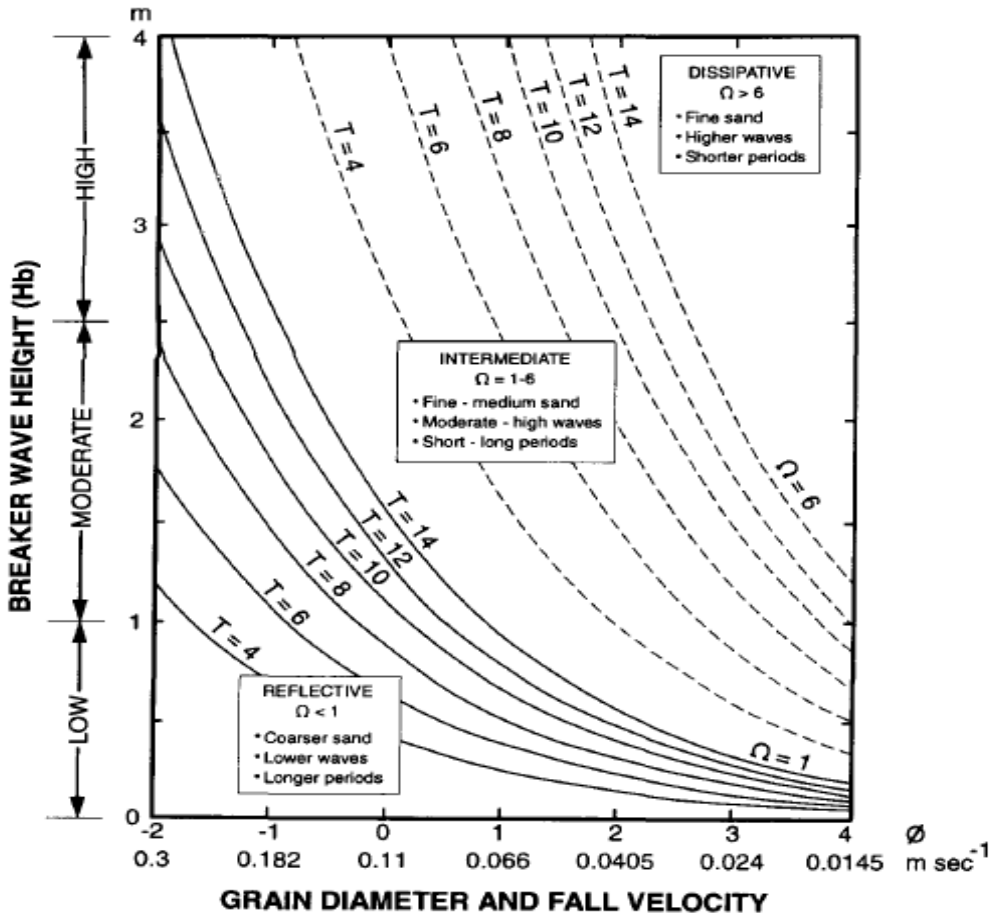

Fig. 2: A plot of breaker wave height versus sediment size, together with wave period that can be used to determine approximate W and beach type. To use the chart determine the breaker height, period and grain size/fall velocity (phi or cm/sec). Read off the wave height and grain size, then use the period to determine where the boundary of reflective/intermediate, or intermediate/ dissipative beaches lie. $\Omega = 1$ along solid T lines, and 6 along dashed T lines. Below the solid lines $\Omega < 1$ the beach is reflective, above the dashed lines $\Omega > 6$ the beach is dissipative, between the solid and dashed lines Ω is between 1 and 6 and the beach is intermediate. (Modified from Short 1986).

Dissipative Shoreline Profile
Milk River, Medicine Hat and SWS Shallow Gas

Short, 1996

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Dissipative, Intermediate and Reflective Shoreline Profiles

Reflective Shoreline Profile
Falher, Viking Conglomeratic Shoreface

Intermediate Shoreline Profile
Belly River, Dunvegan

Dissipative Shoreline Profile
Milk River, Medicine Hate and SWS Shallow Gas

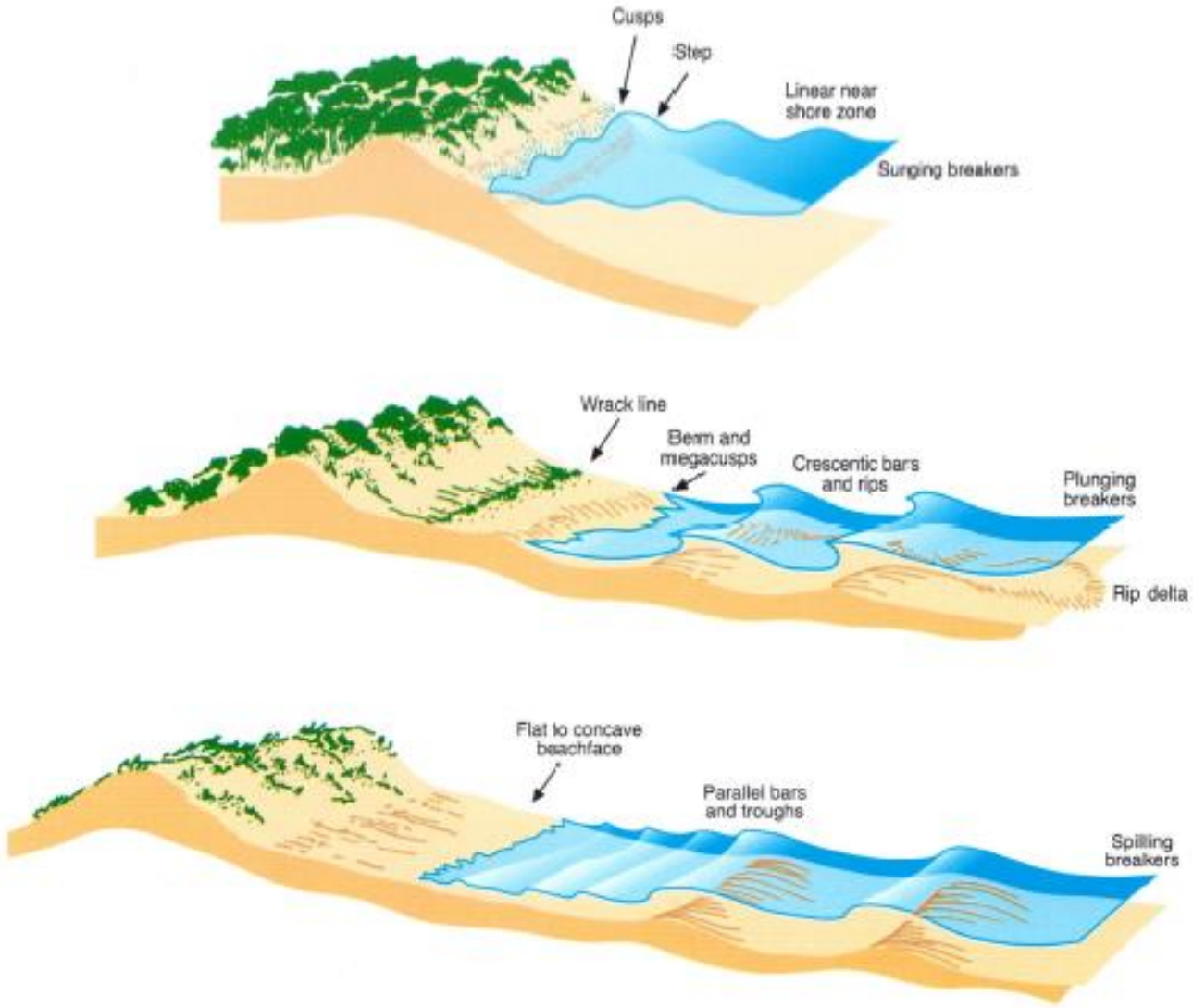

Figure 1. Schematic diagrams of the three micro-tidal surfzone-beach types, dissipative, intermediate and reflective. Also shown are the typical (for temperate environments) foredune stages and vegetation cover (modified from [Hesp, 2000]).

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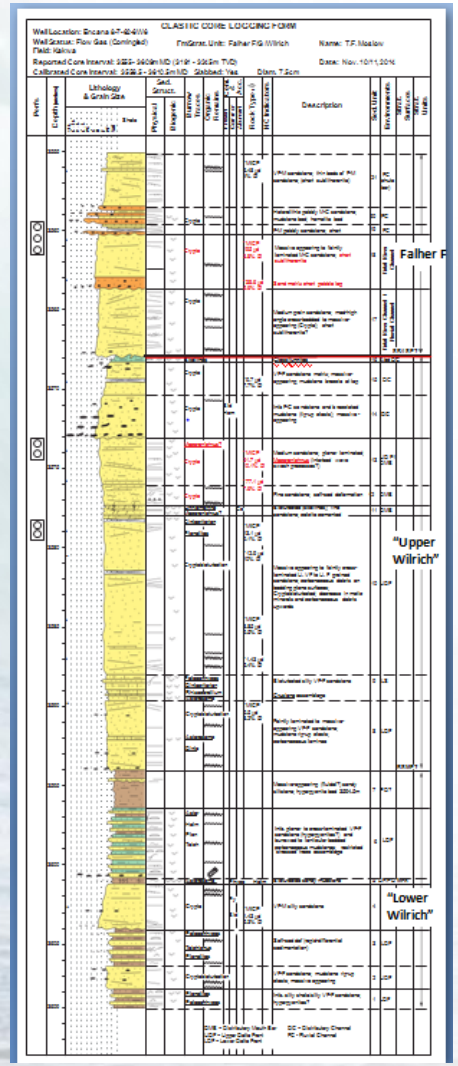
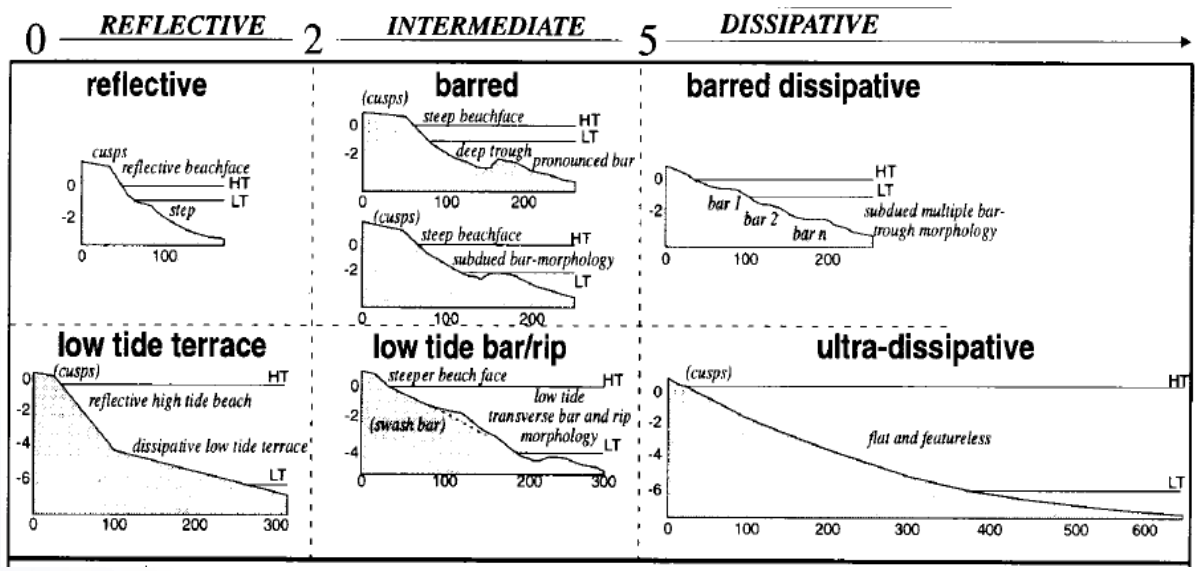
Conventional – Unconventional Continuum

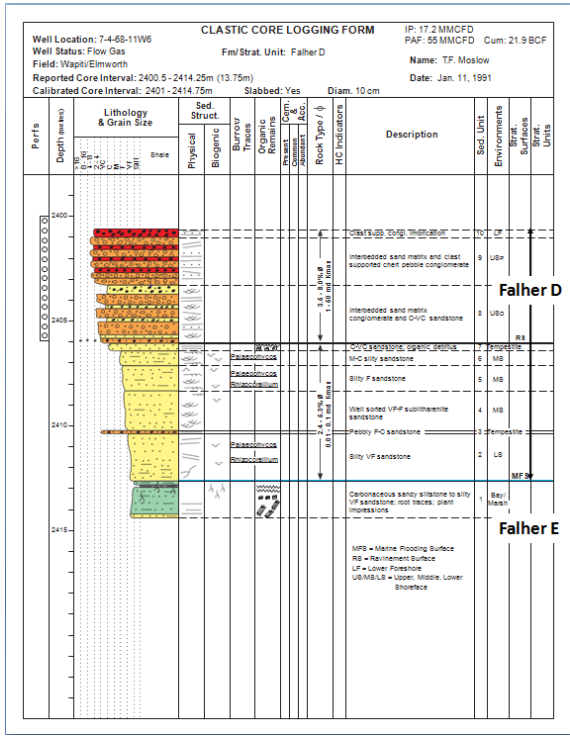
8-7-62-6W6





Short, 1996

7-4-68-11W6



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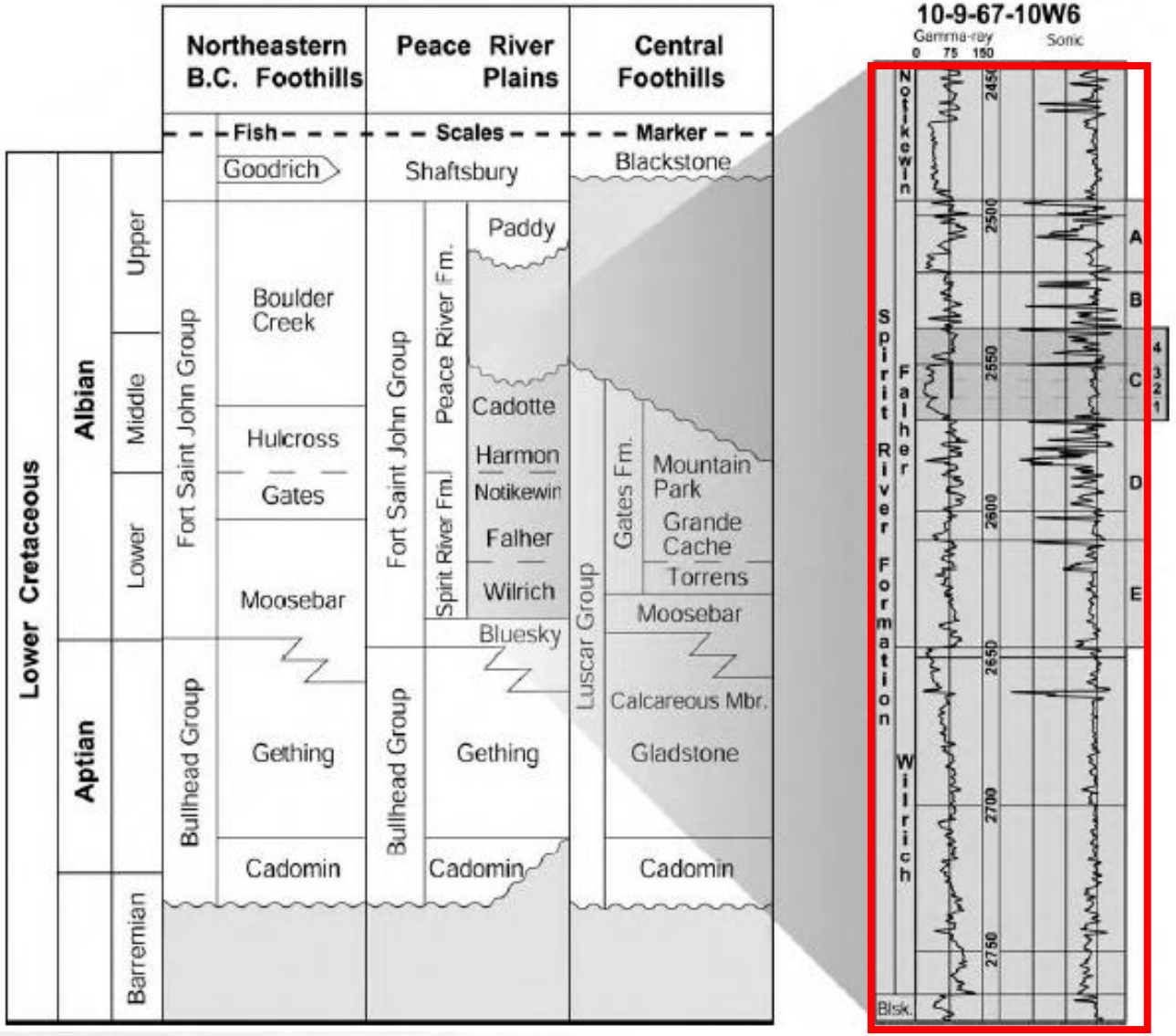
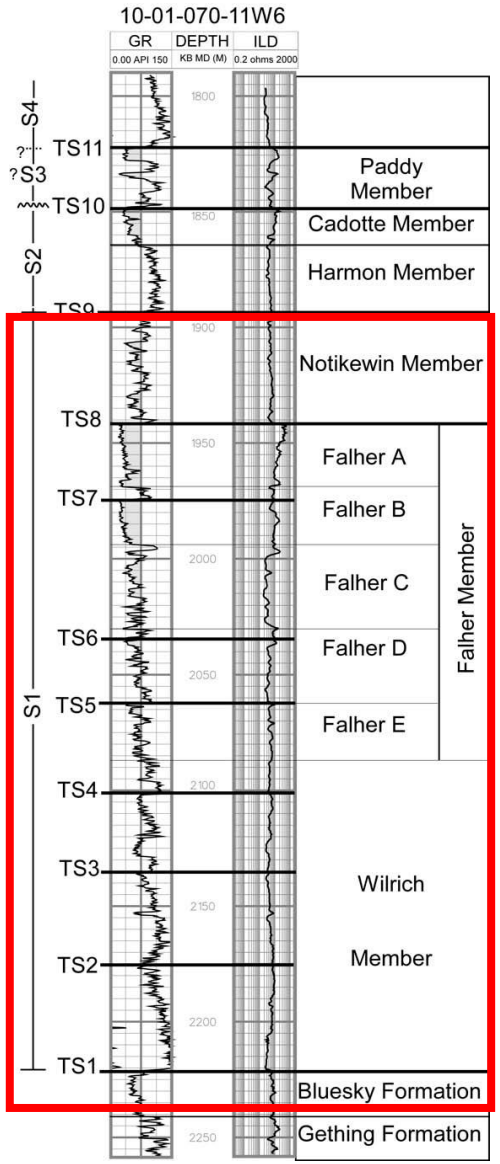
Stratigraphy – Fort St. John – Spirit River Groups





Modified after Masters, 1984

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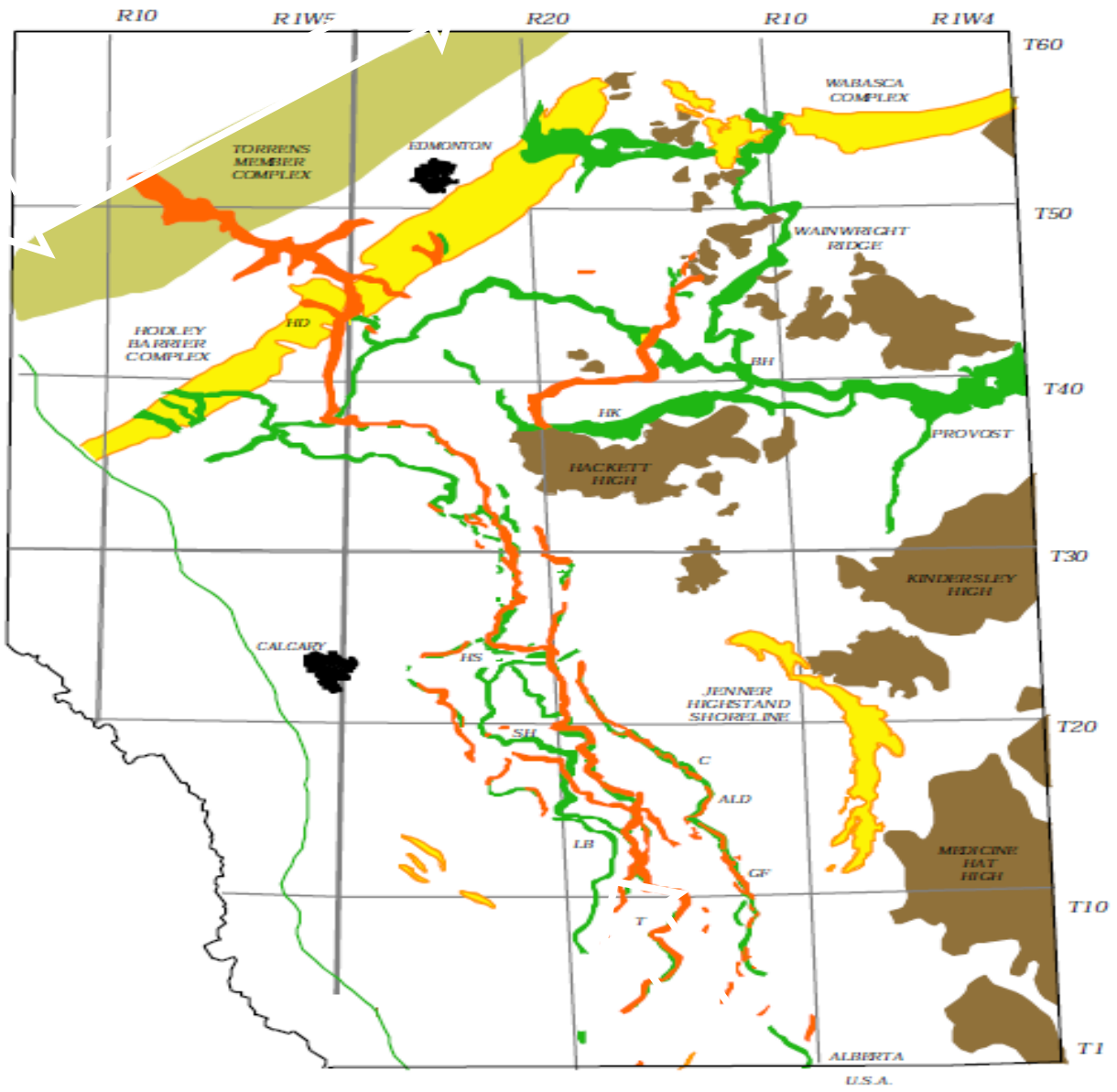
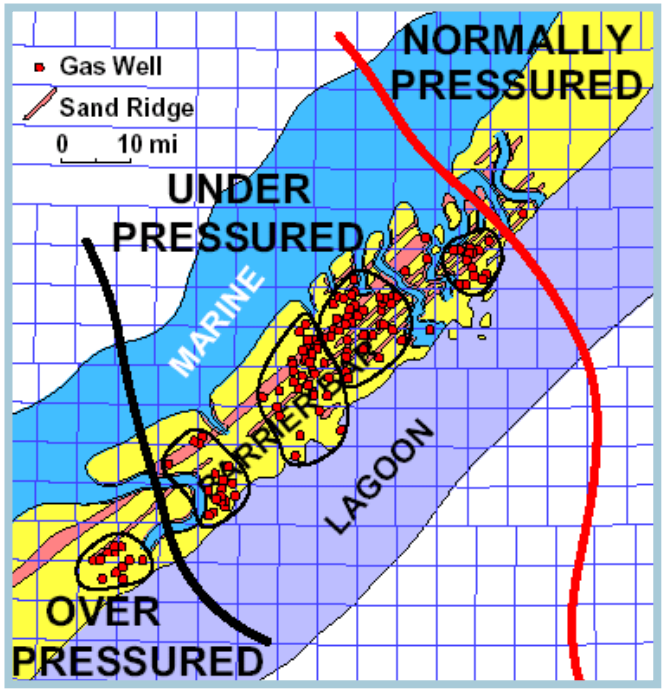
Glauconitic Paleogeography



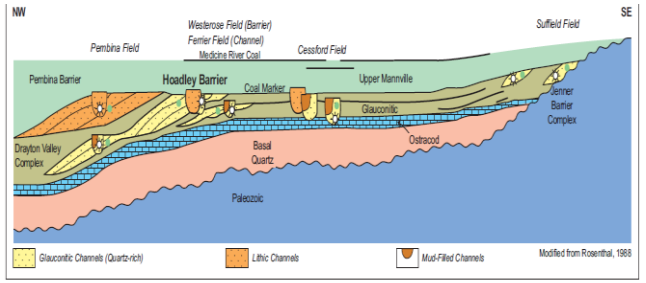
Shorelines

GLCC Age Channels

Post GLCC Incised Valley fill deposits



Surdam, 1997, modified from Chiang, 1984



CDD

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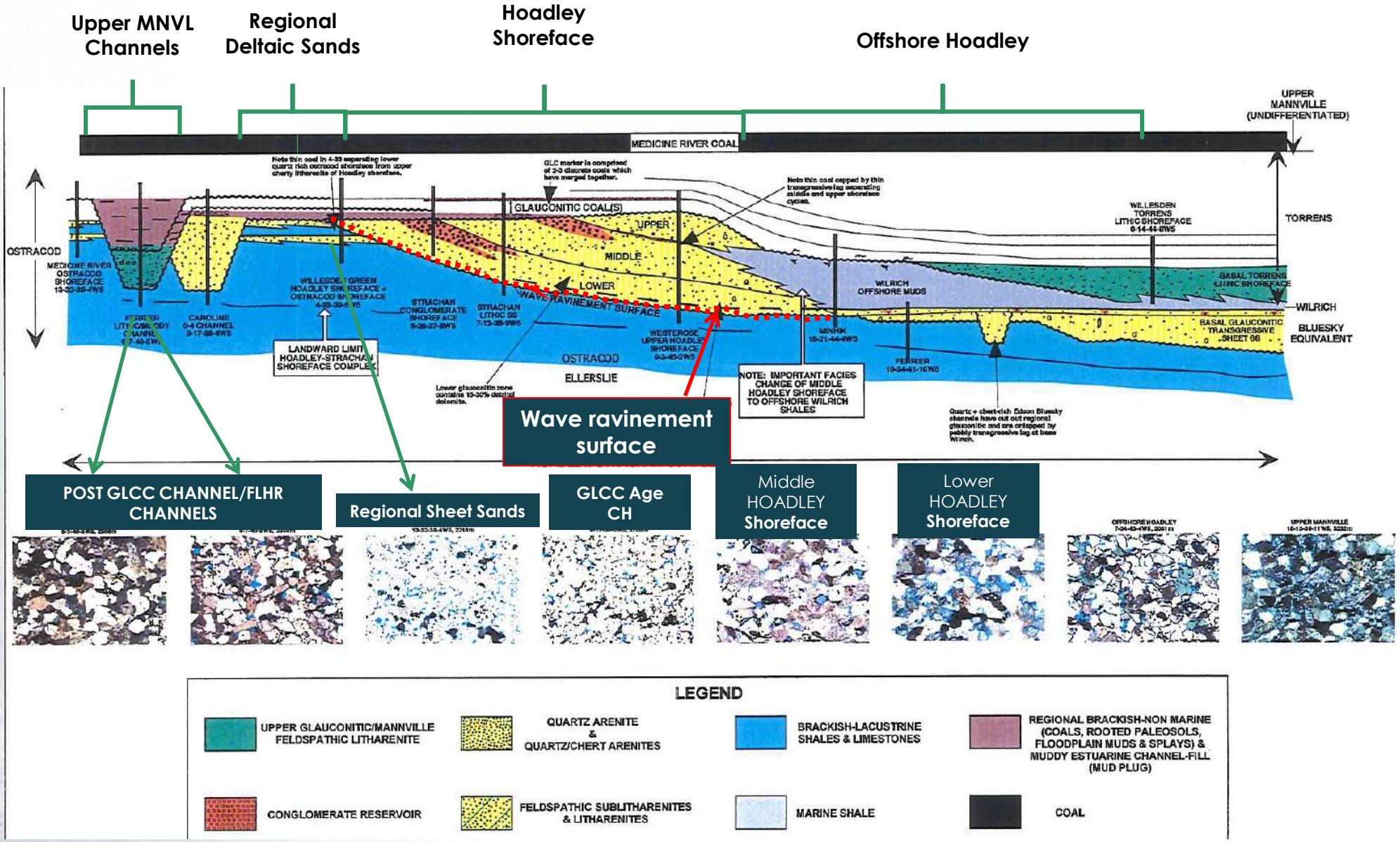
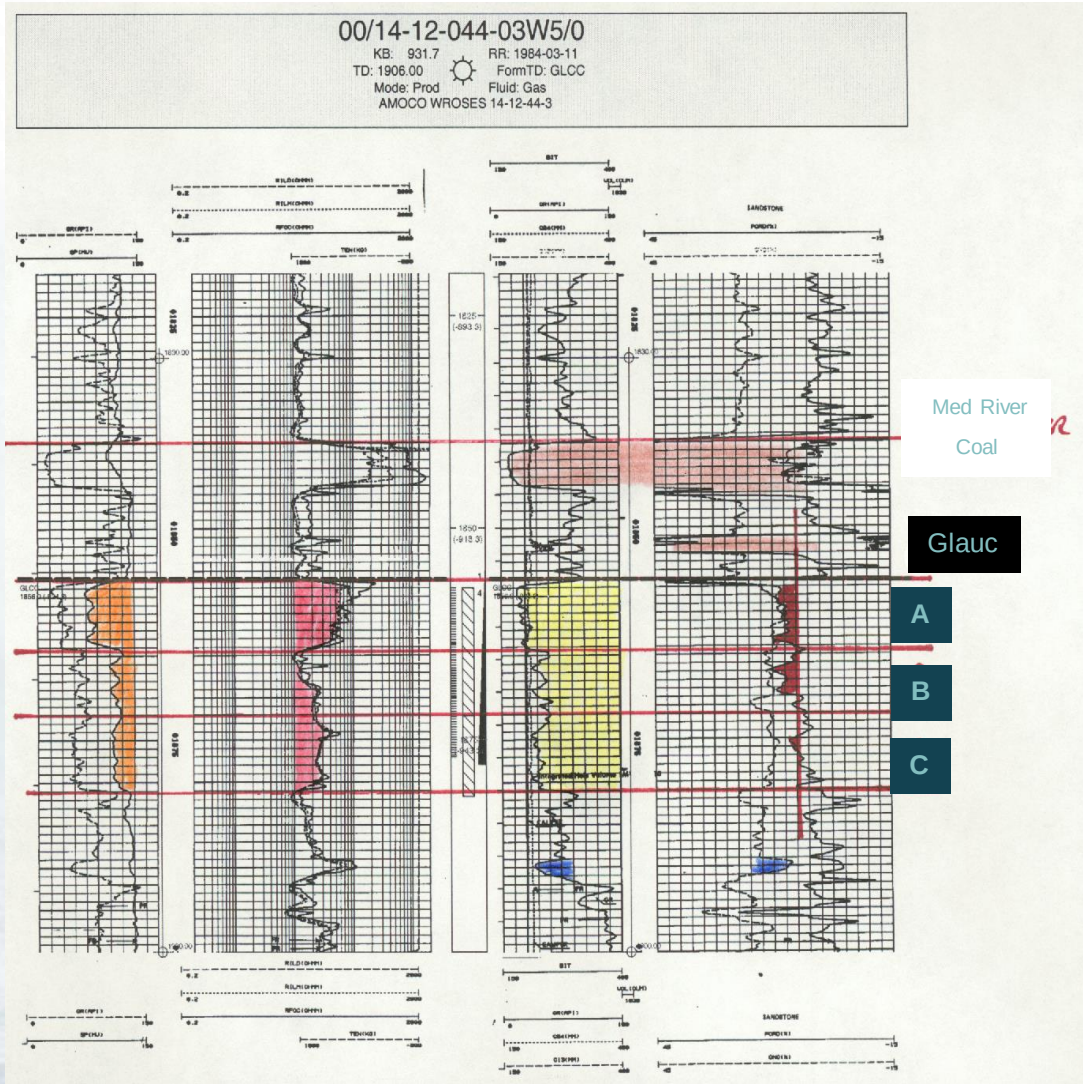
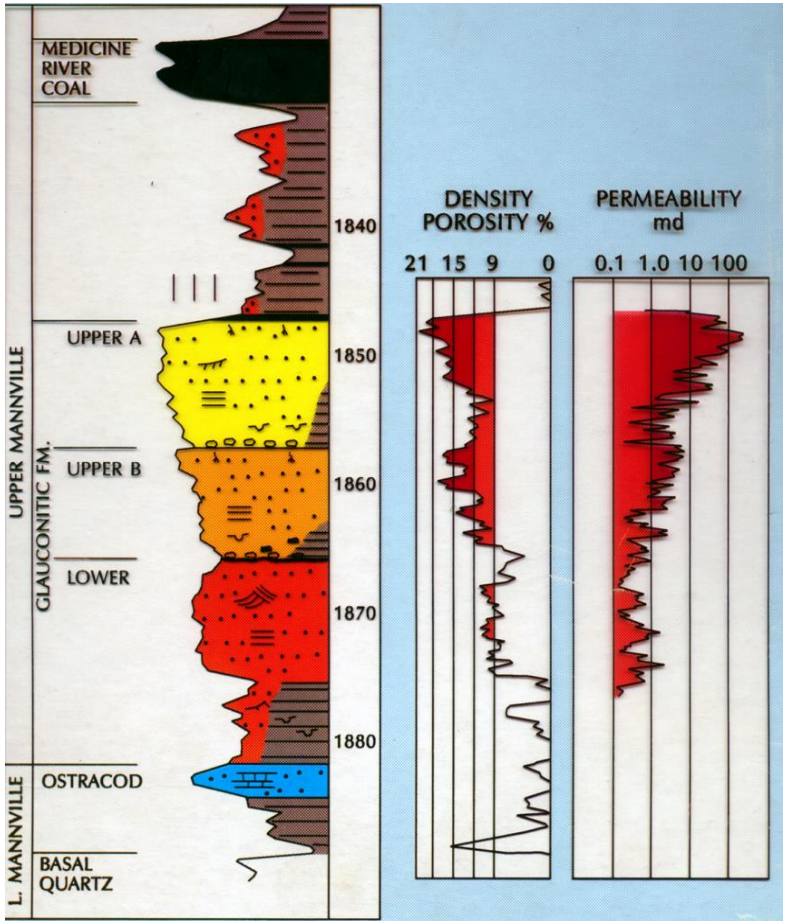
Glauconitic Hoadley Type Schematic Cross Section SE-NW



Simons, 2015; modified after Rosenthal, 1998

Example Log – Hoadley Barrier





modified after Rosenthal, 1998

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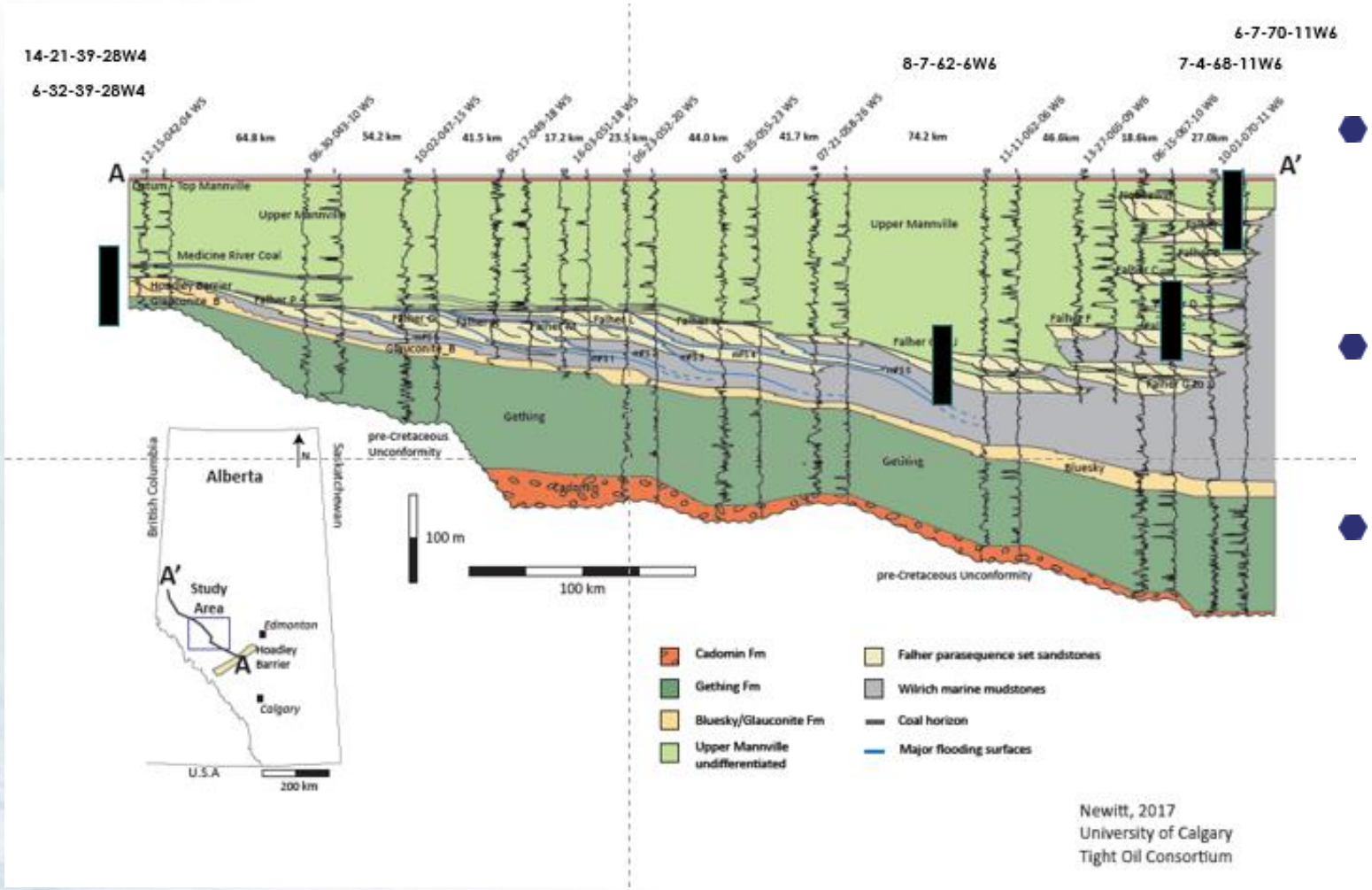
Spirit River Members



- **Notikewin** Member
  - Fine to medium grained argillaceous sandstone, dark shale, ironstone
  - Max thickness 28m
- **Falher** Member
  - Greywacke, shale, siltstone, coal
  - Max thickness 215m
- **Wilrich** Member
  - Dark shales, with thin interbedded sandstone and siltstone stringers
  - Max thickness 154m

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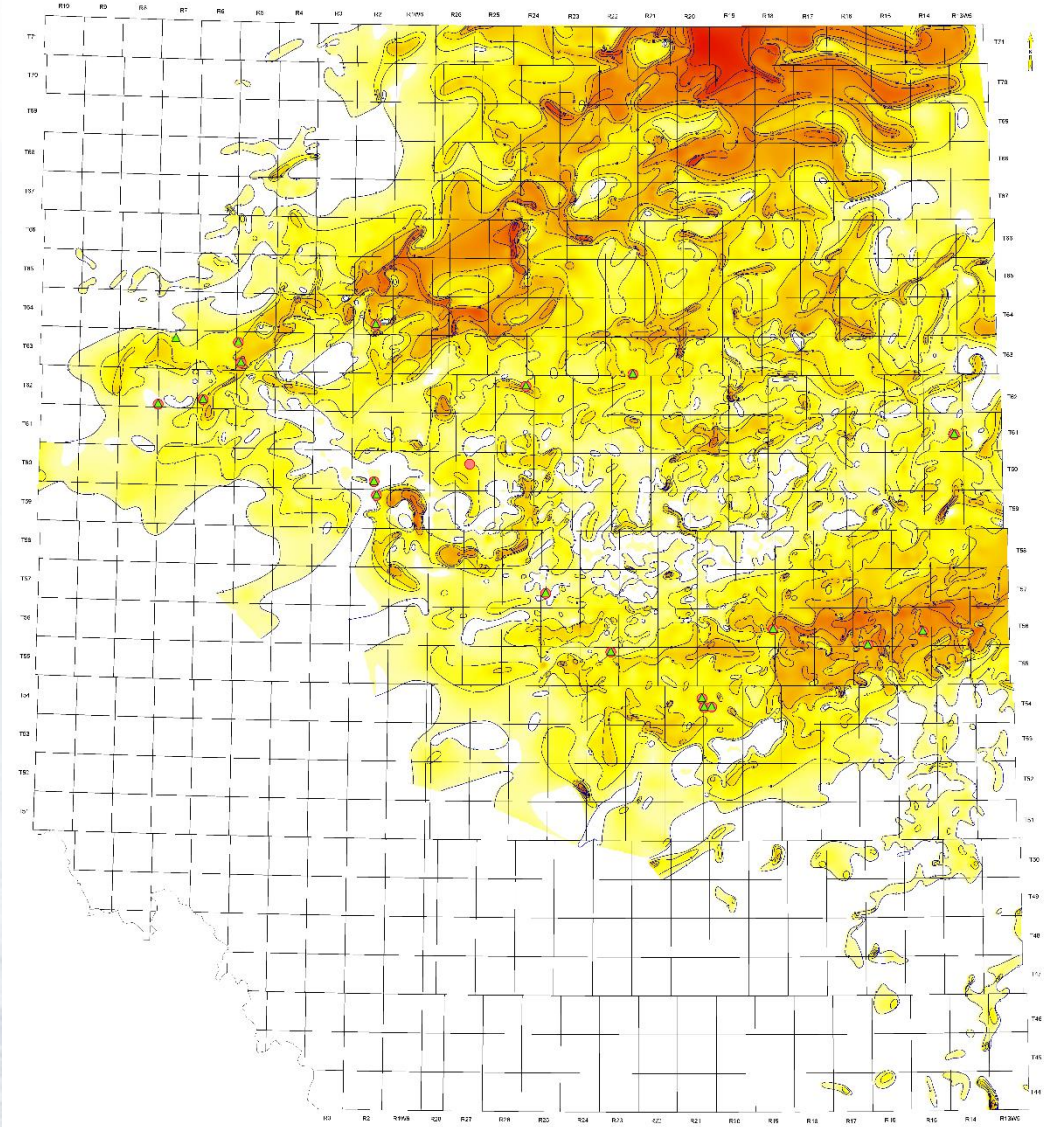
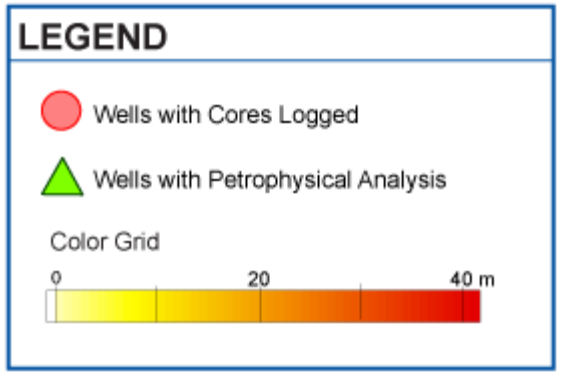
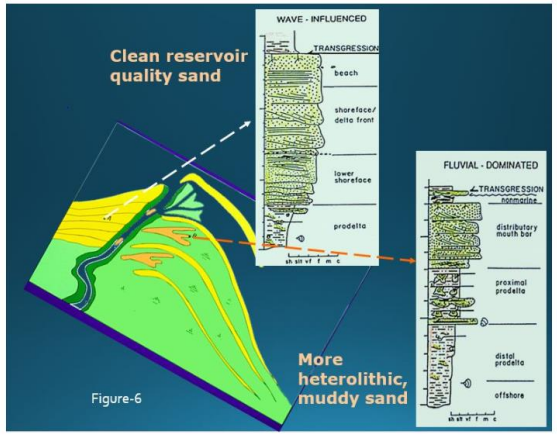
Wilrich A – Net Porous Sand







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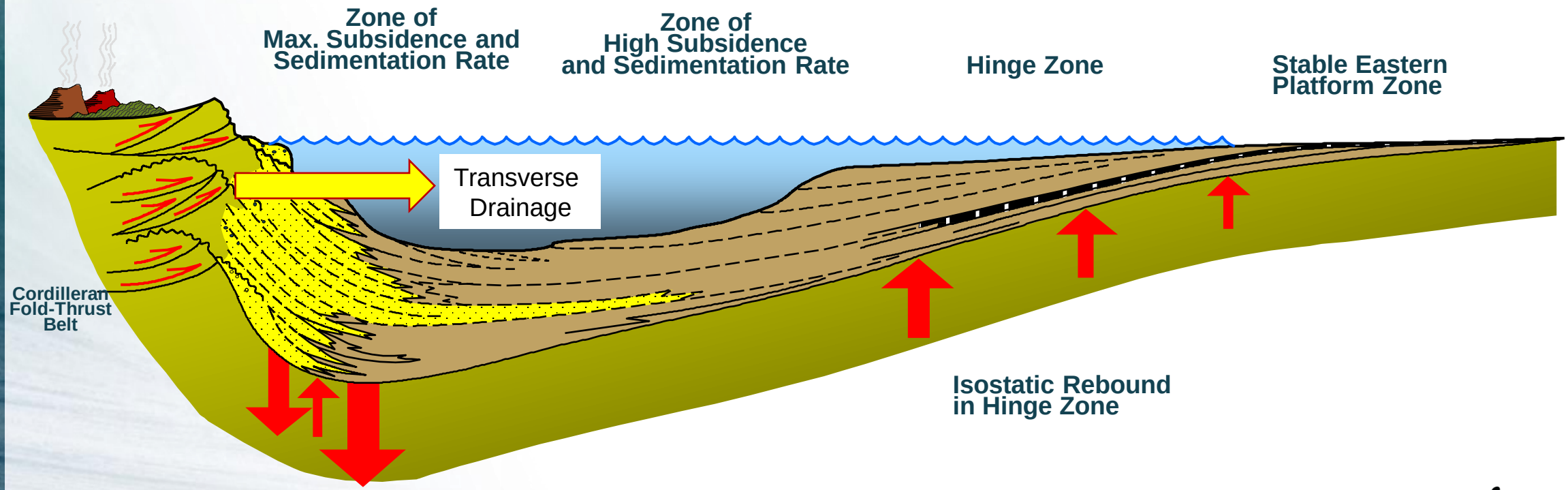
Foreland Basin
Axial Drainage vs. Transverse Drainage
Overfilled FB

Overfilled Foreland Basin

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado



modified after Kauffman, 1984

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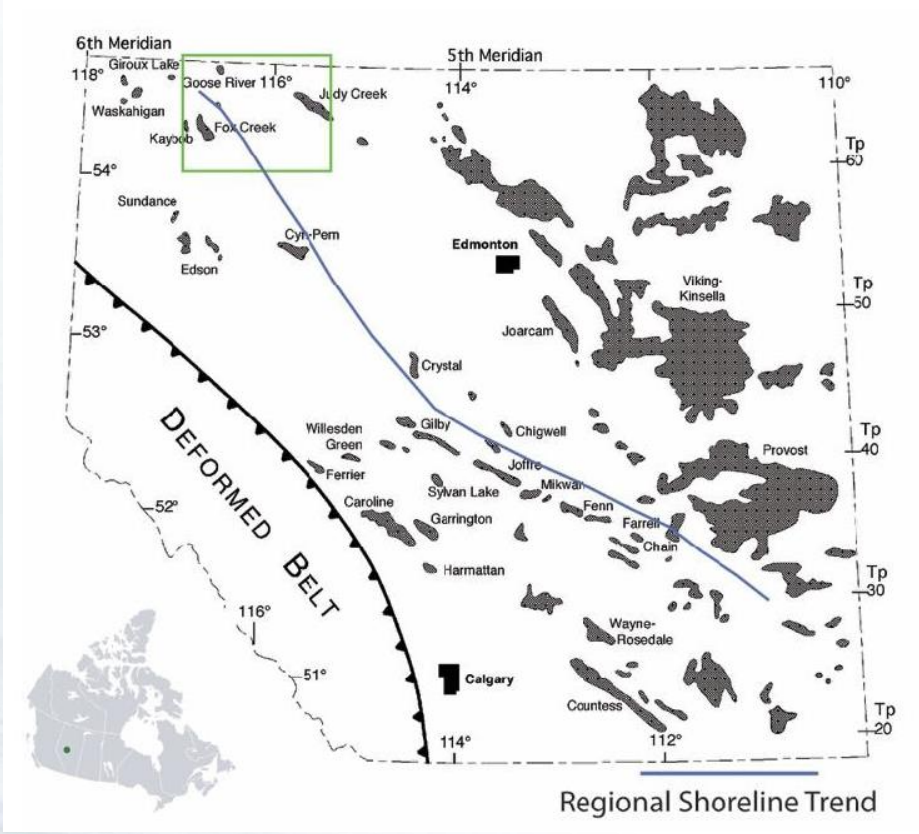
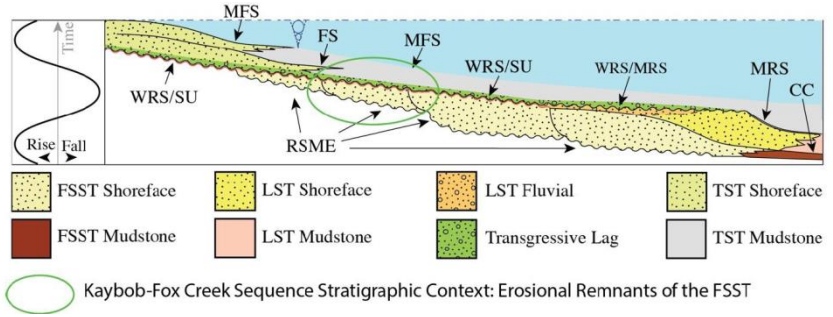
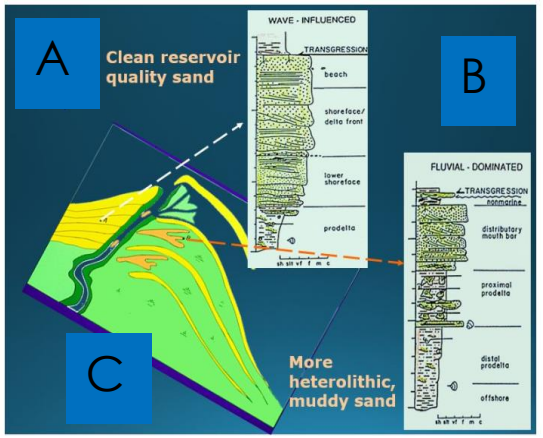
Forced Regressive Asymmetric Delta of the Lower Cretaceous Viking Formation, Kaybob-Fox Creek Fields, Alberta, Canada Overfilled FB Transverse Drainage





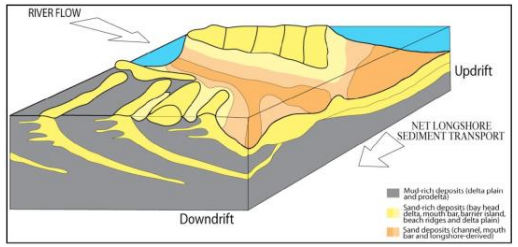
Kaybob – Fox Creek Sequence Stratigraphic Context: Erosional Remnants of the Falling Stage Systems Track (FSST)

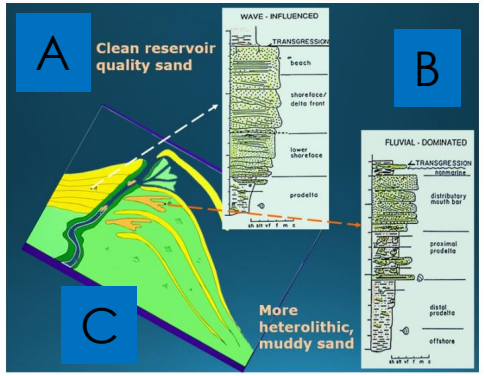


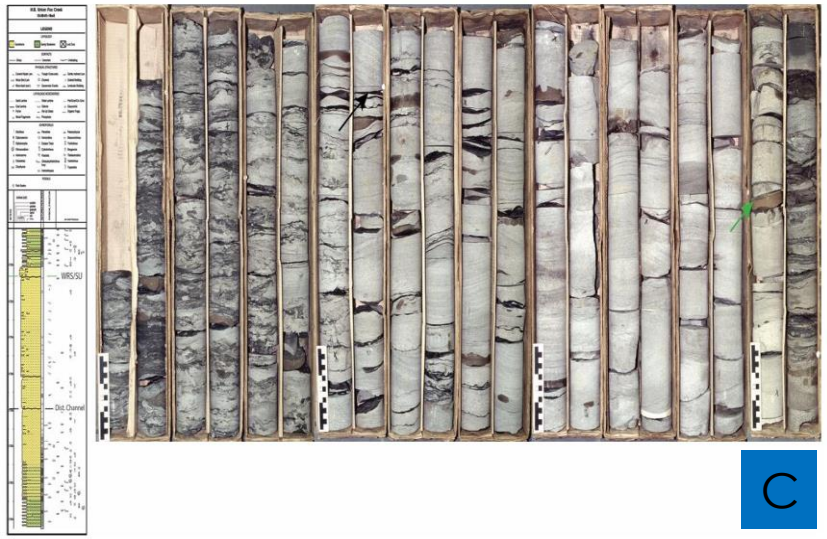
MacEachern, 2016

ZAITLIN GEO CONSULTING LTD.

Forced Regressive Asymmetric Delta of the Lower Cretaceous Viking Formation, Kaybob-Fox Creek Fields, Alberta, Canada







MacEachern, 2016

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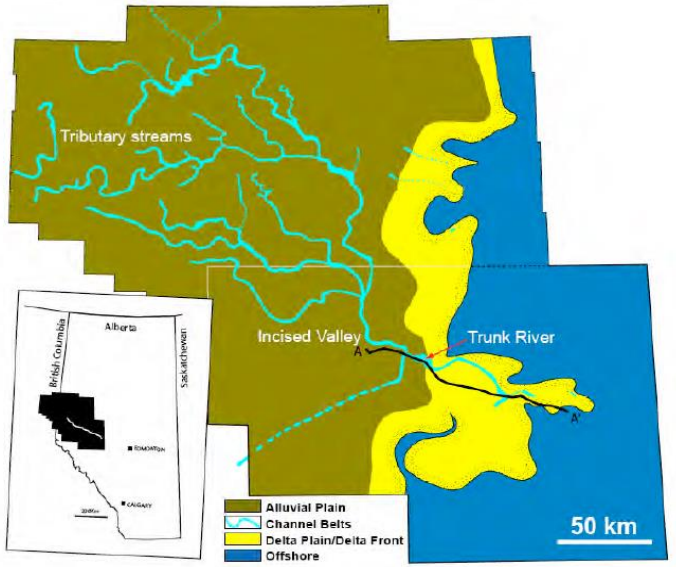
Dunvegan Formation

Bhattacharya and MacEachern, 2010

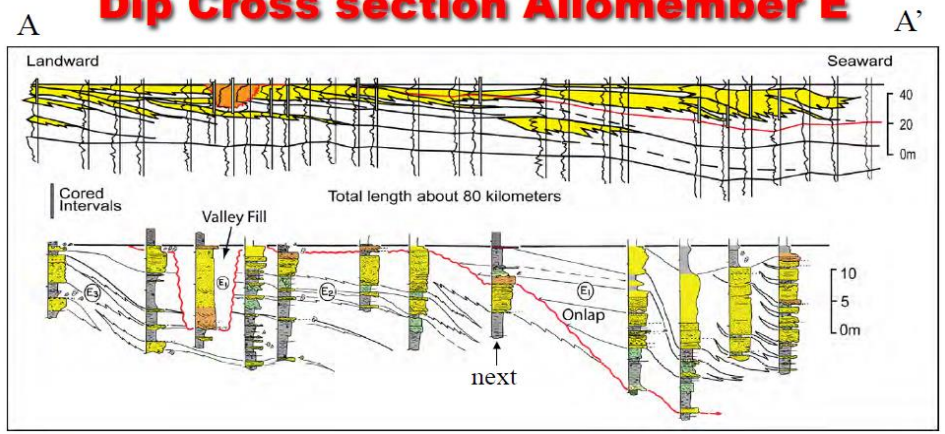
Dunvegan Paleogeography

- Tributive valley systems feed trunk rivers and major delta lobes.
- Feeder valleys can be linked to delta and prodelta.
- Cross section A-A' in next slide.



Plint and Wadsworth, 2003

Dip Cross section Allomember E



- Feeder valleys can be linked to age-equivalent delta and prodelta facies.

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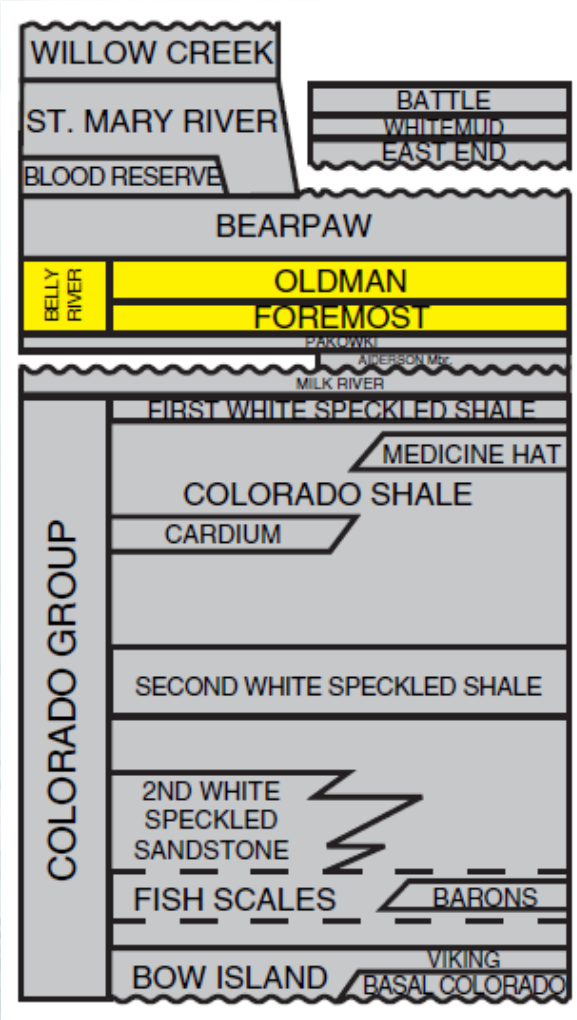
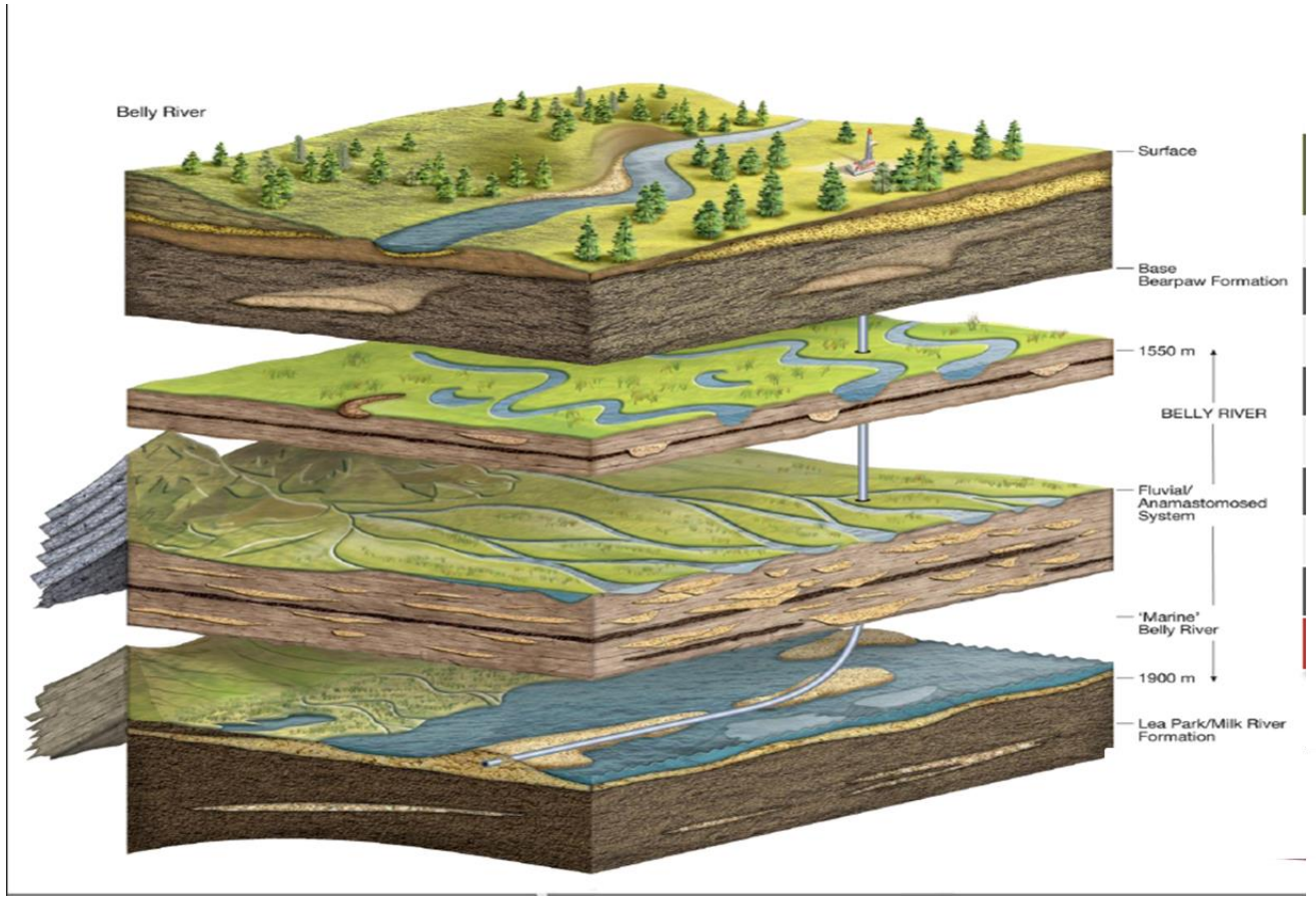
Belly River Formation

Stratigraphy



Depositional Model



Boulder Corporate Presentation, 2015

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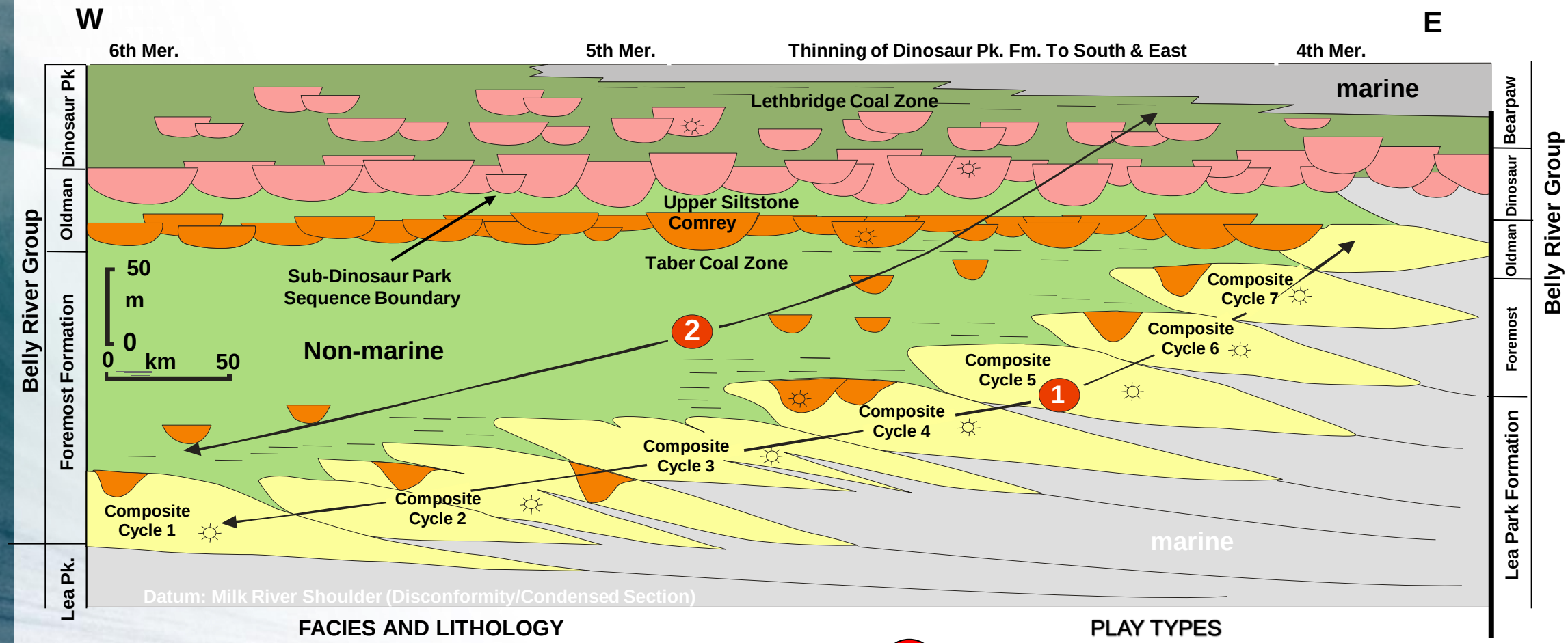
Belly River Group
Stratigraphy and Play Types



FACIES AND LITHOLOGY

- Non-marine sandstone & siltstone with coal
- Shoreline - related sandstone
- Shallow marine siltstone/shale
- Fluvial channel or valley-filled estuarine ss

PLAY TYPES

1. Basal Belly River shoreface sandstones
2. Belly River Gp. Fluvial channel sandstones (Foremost, Oldman and Dinosaur Park Fms.)

Productive Reservoirs - Gas/Oil

After Hamblin, 1996a, 1997a/b

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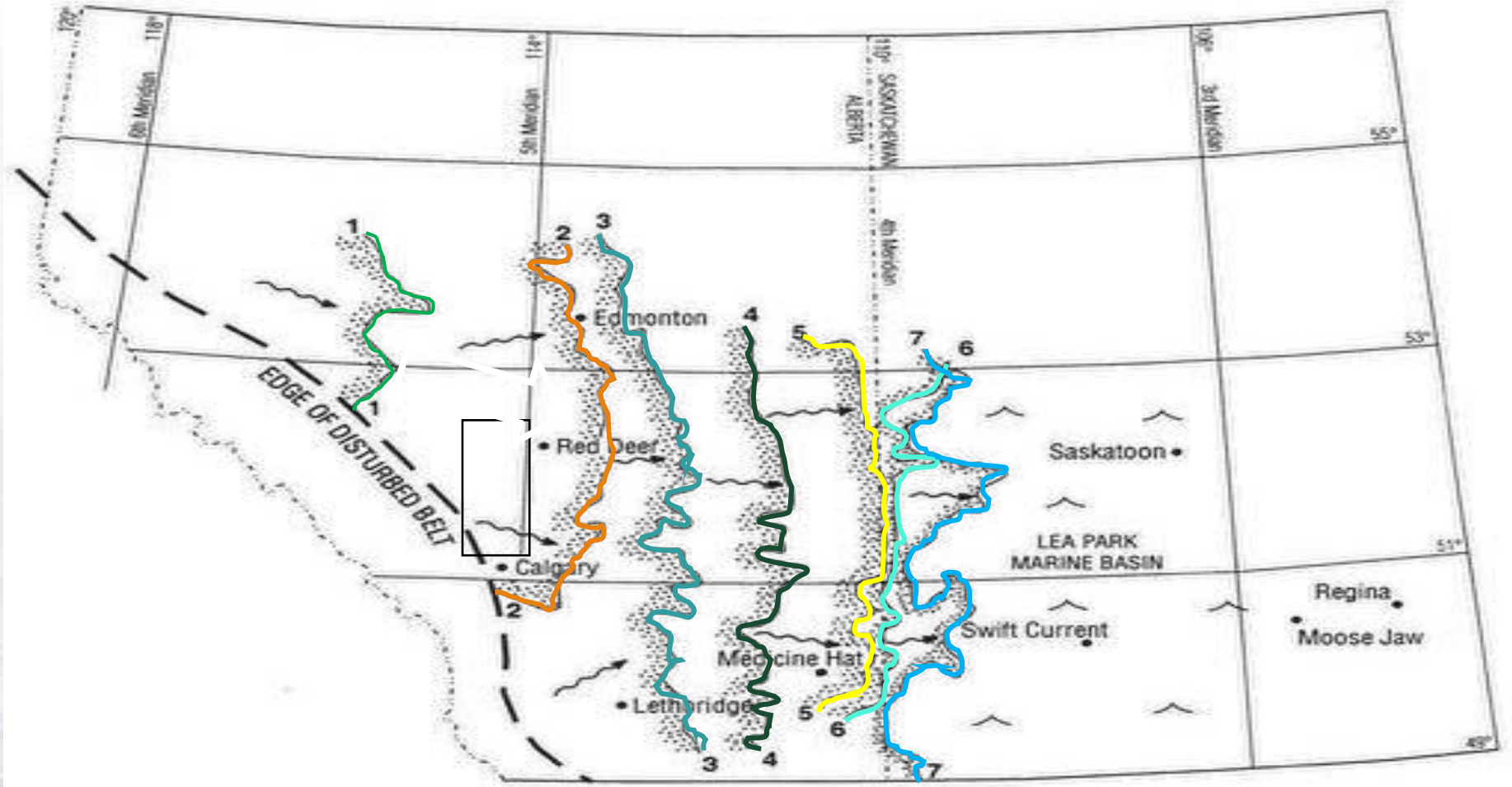
Basal Belly River Prograding Shorelines Overfilled Foreland Basin



After Hamblin,1996a,1997a/b

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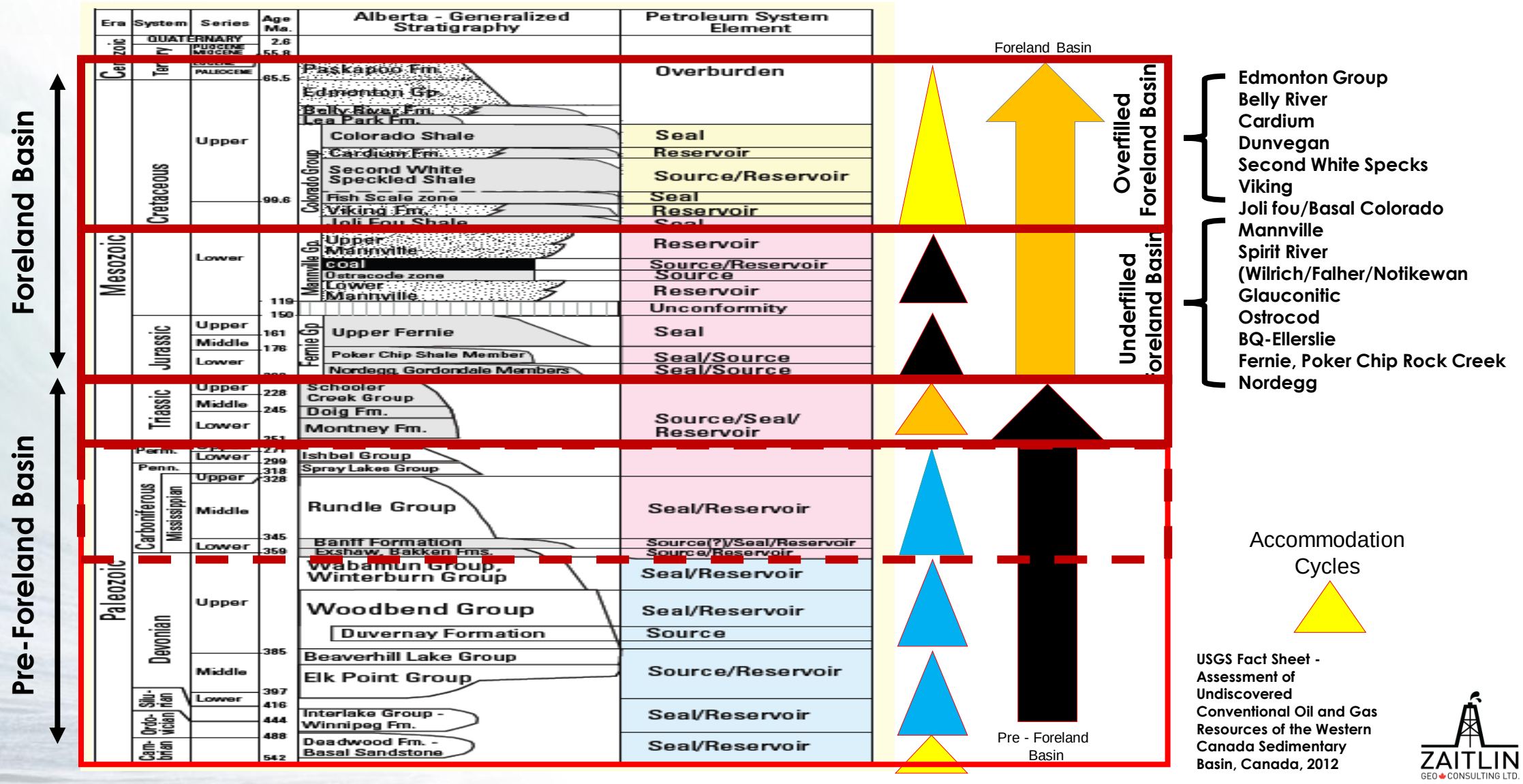
Western Canada Sedimentary Basin (WCSB)



USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012

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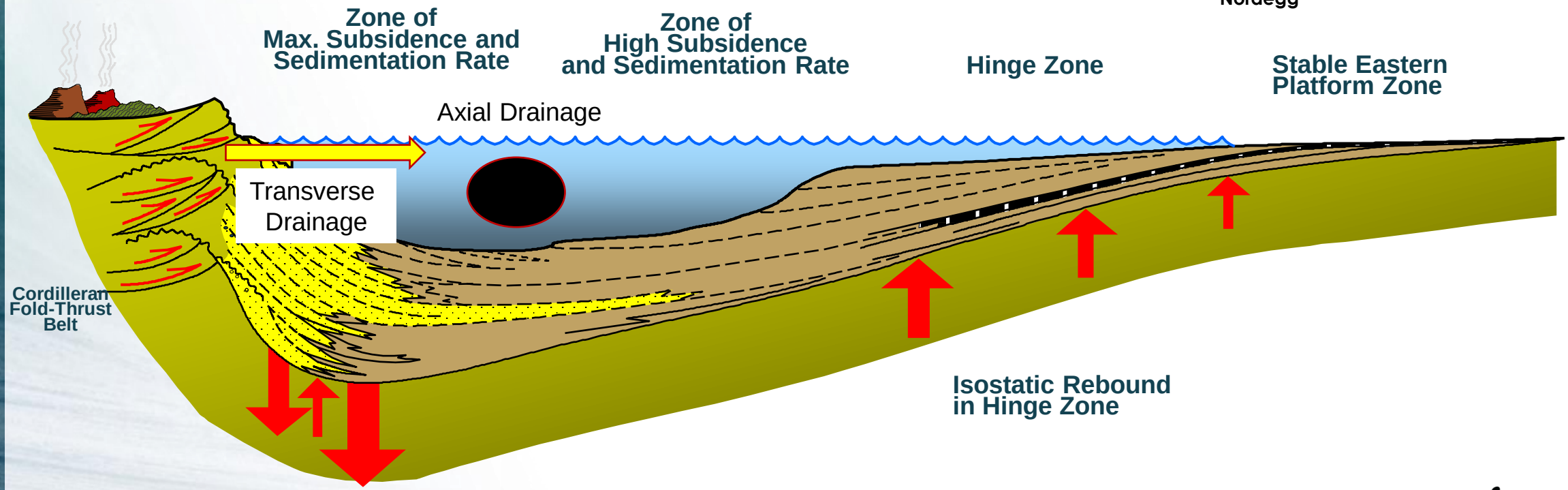
Foreland Basin
Axial Drainage vs. Transverse Drainage
Underfilled FB vs. Overfilled FB

Overfilled Foreland Basin

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado

Underfilled Foreland Basin

- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan
- Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg



modified after Kauffman, 1984

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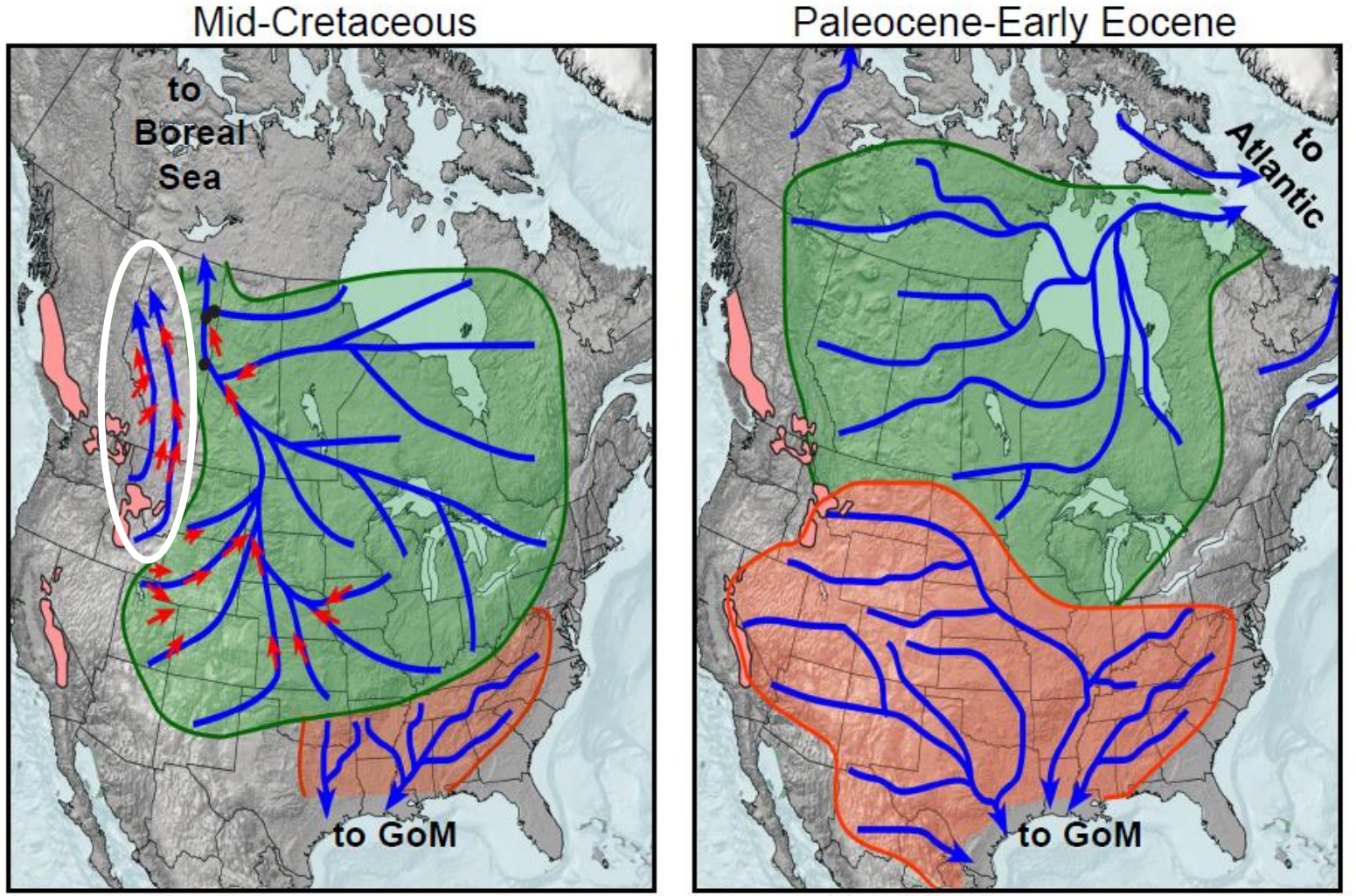
Continental Scale Paleodrainage Reorganization

Underfilled Axial Foreland Basin Drainage to north



Overfilled Transverse Foreland Basin Drainage to East

Blum et al., 2015

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  - PanCanadian/Encana
  - Suncor
  - Enerplus
  - EOG
  - Daylight/Midnight/Pace
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  - University of Ottawa
  - University of Sydney

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