



Variations in Paleodrainage and Depositional Style:

Underfilled and Overfilled Foreland (Deep Basin) Western Canada Sedimentary Basin

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Outline

- **Key Points**
- **Geologic Setting**
 - **Basin Tectonics, Compartmentalization, Accommodation, Stratigraphy, Source Rocks, Deep Basin Pressure Systems, Porosity styles, Shoreline models (Asymmetrical Delta Model)**
- **WCSB Drilling Activity**
- **Underfilled vs. Overfilled Foreland Basin**
 - **Underfilled FB: e.g. Nordegg, Nikinassin, BQ and equivalents, Spirit River**
 - **Overfilled FB: e.g. Dunvegan, Belly River Formations**
- **Summary and Conclusions**
- **Acknowledgements**

Key Points

- **Four key plays actively being pursued presently in the WCSB**
 - **Duvernay, Montney, Spirit River (Wilrich), Viking**
- **WCSB Foreland Basin is divisible into:**
 - **Underfilled Foreland Basin sequence**
 - **Overfilled Foreland Basin sequence**
 - **Pre-Foreland Basin sequence**
- **Paleodrainage:**
 - **South to north for the underfilled foreland basin**
 - **West to east for the overfilled foreland basin**
- **Shoreline geometry**
 - **East - west for the underfilled foreland basin - Prograding to the north**
 - **North – south for the overfilled foreland basin - Prograding to the east**

Major North American Unconventional Plays



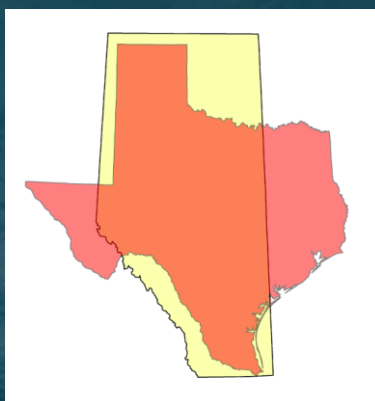
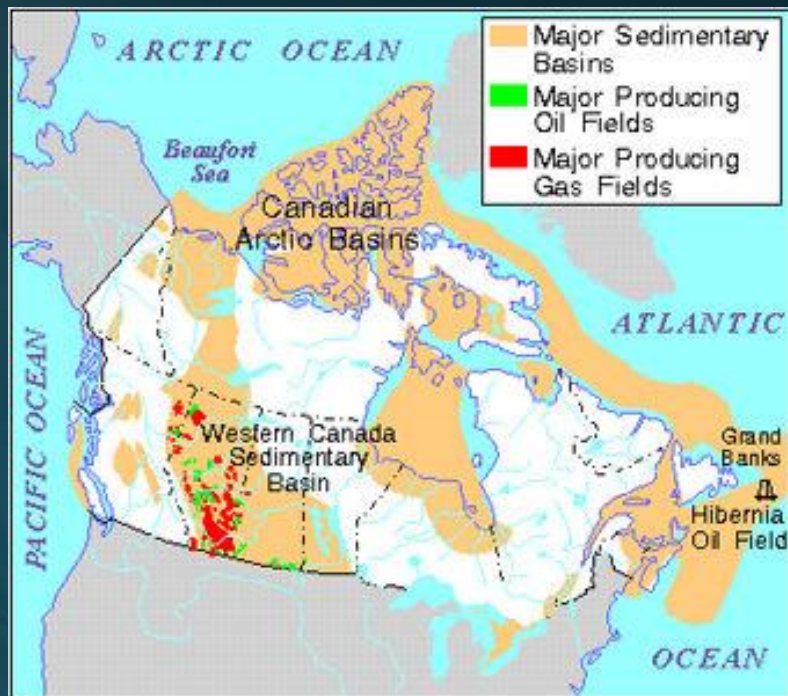
“..... best strategy is to focus on growth companies with the lowest cost structures in the best basins and ‘cash harvesters’ with low sustaining capital requirements.” BMO Capital Markets O&G: North America Jan 16, 2017

➤ 5 Main areas

Questions:

- 1- Is the Western Canada Sedimentary Basin a “best in class basin”?
- 2- What are the active plays presently in the WCSB?

Oil and Gas in the WCSB

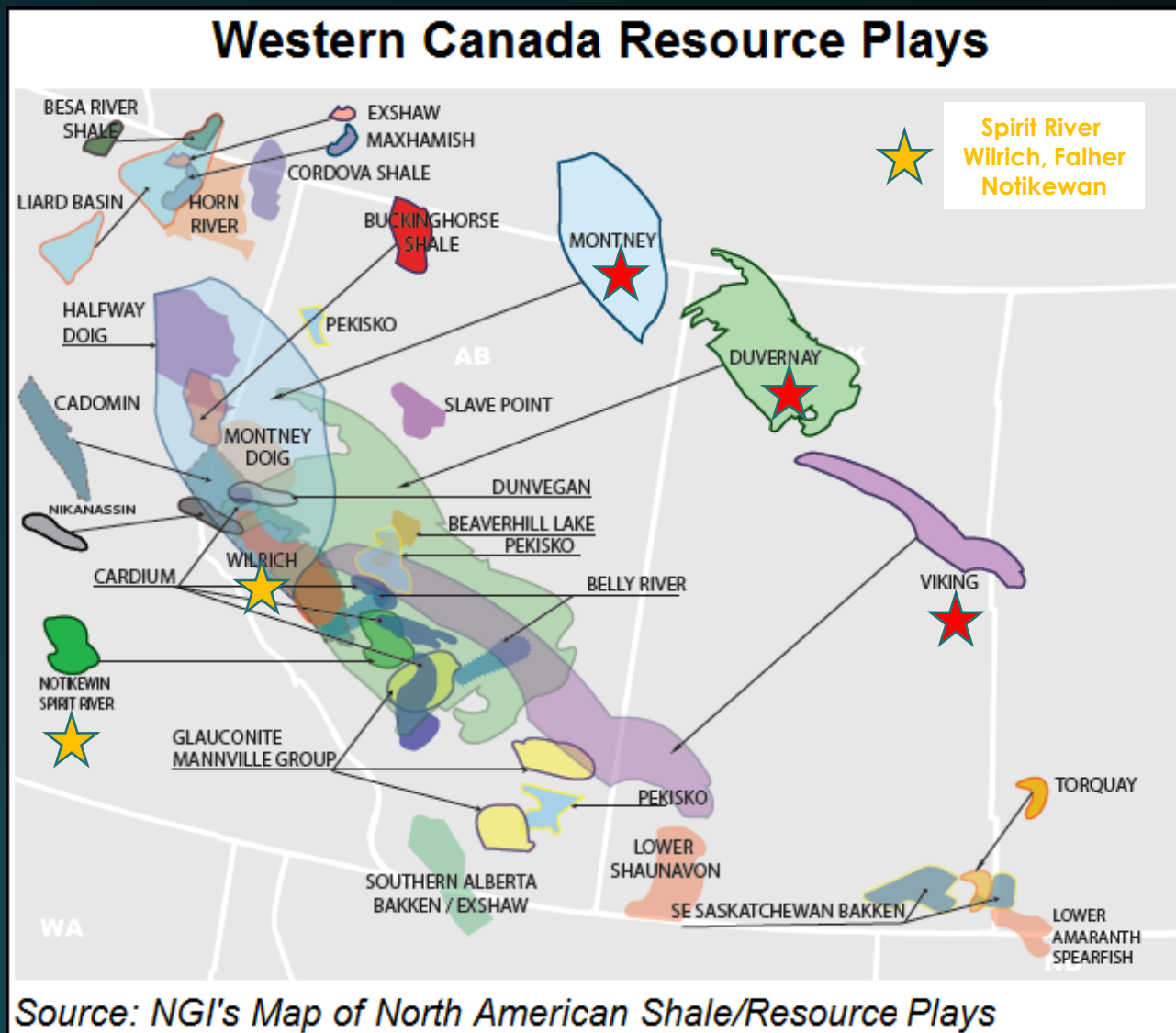


Alberta

Area: 661,848 km²

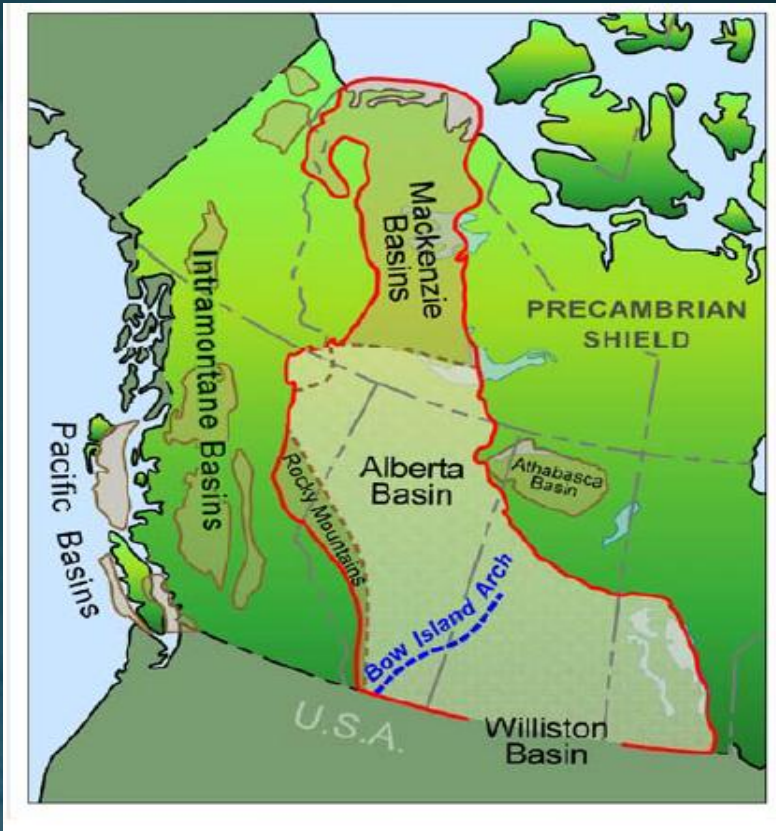
Texas

Area: 696,241 km²



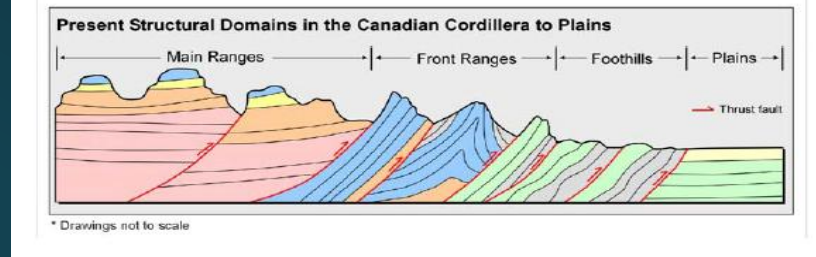
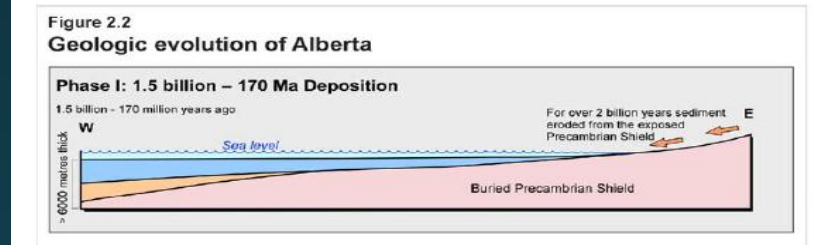
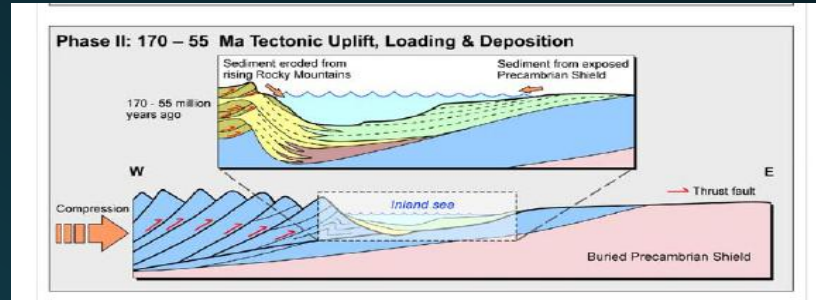
Source: NGI's Map of North American Shale/Resource Plays

Western Canada Sedimentary Basin Tectonic Evolution



Foreland Basin

Pre-Foreland Basin

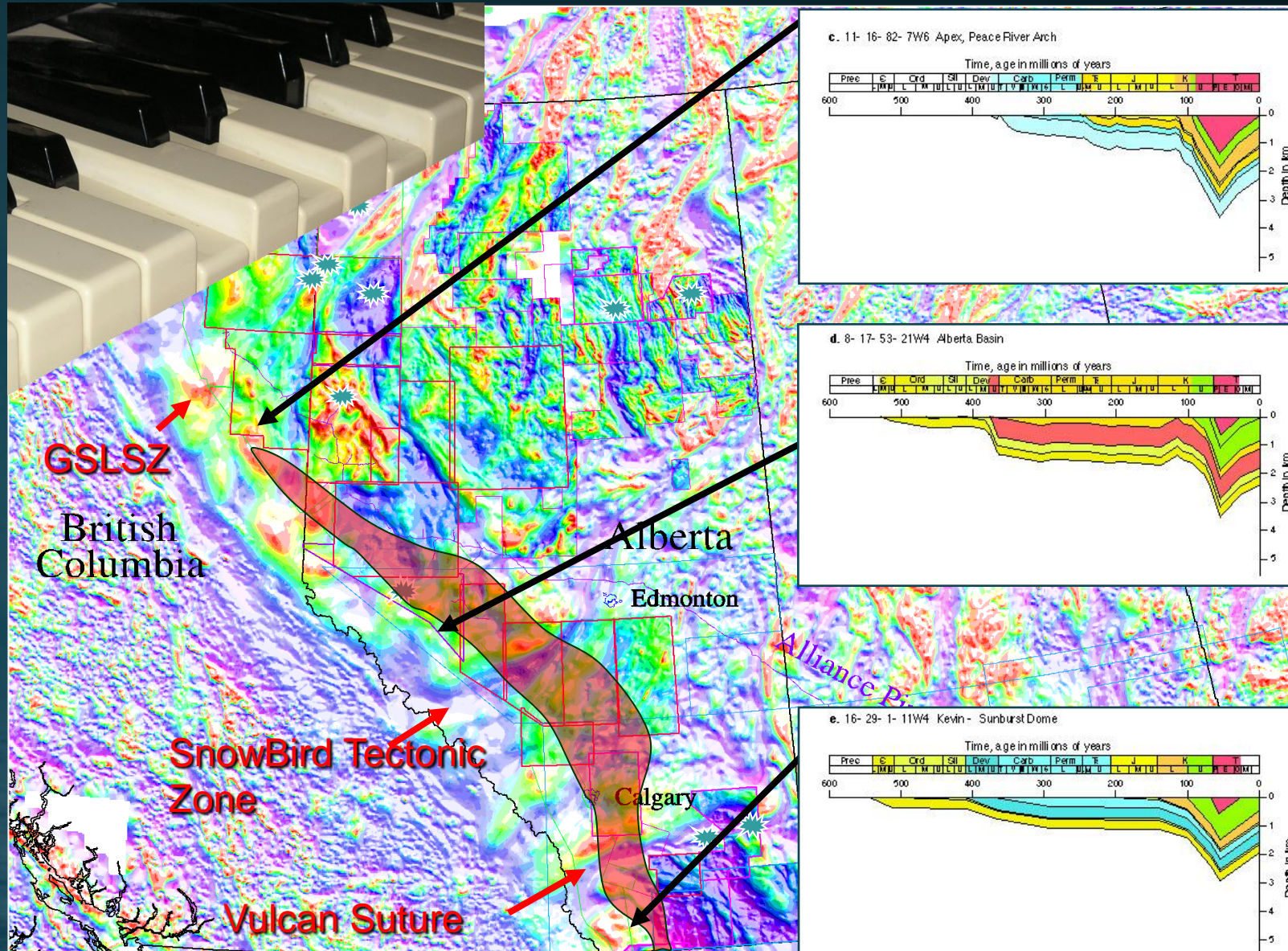


- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli fou/Basal Colorado

- Mannville
- Spirit River
- (Wilrich/Falher/Notikewan)
- Glaucconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordeg

Burial History Curves

Compartmentalization of the WCSB Shear Zone "Piano Key" Effect



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

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)

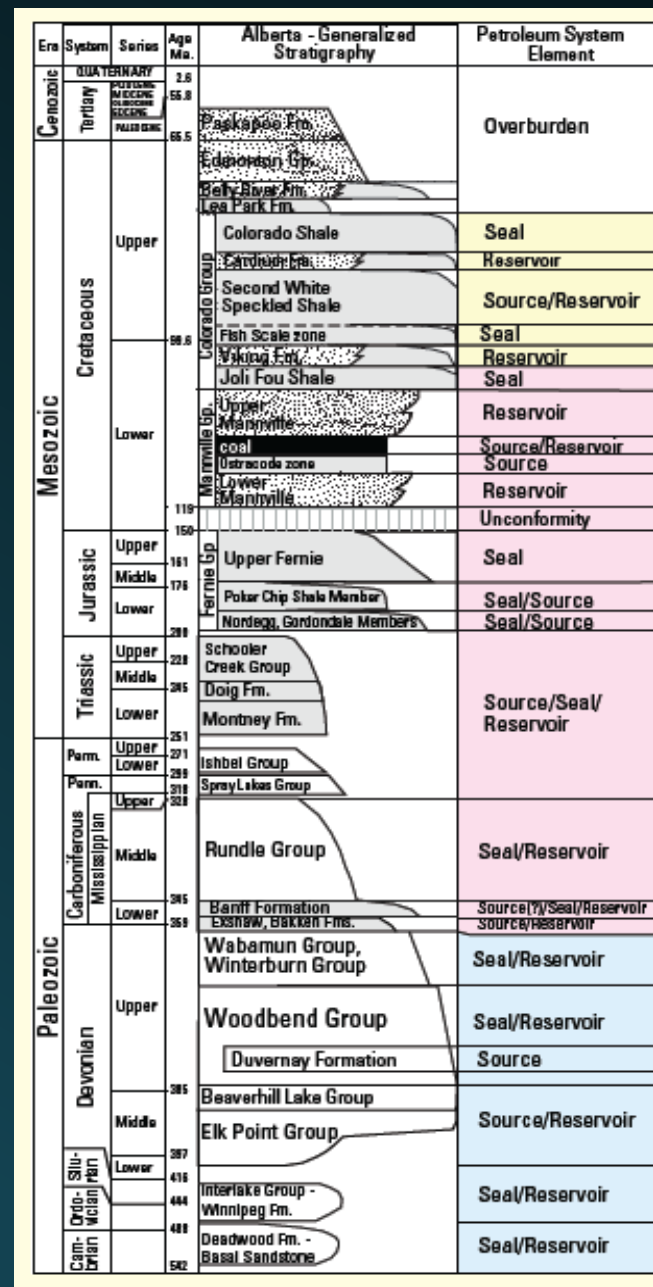
- Ostracod
- Fernie/Poker Chip
- Nordegg

Pre- Foreland Basin

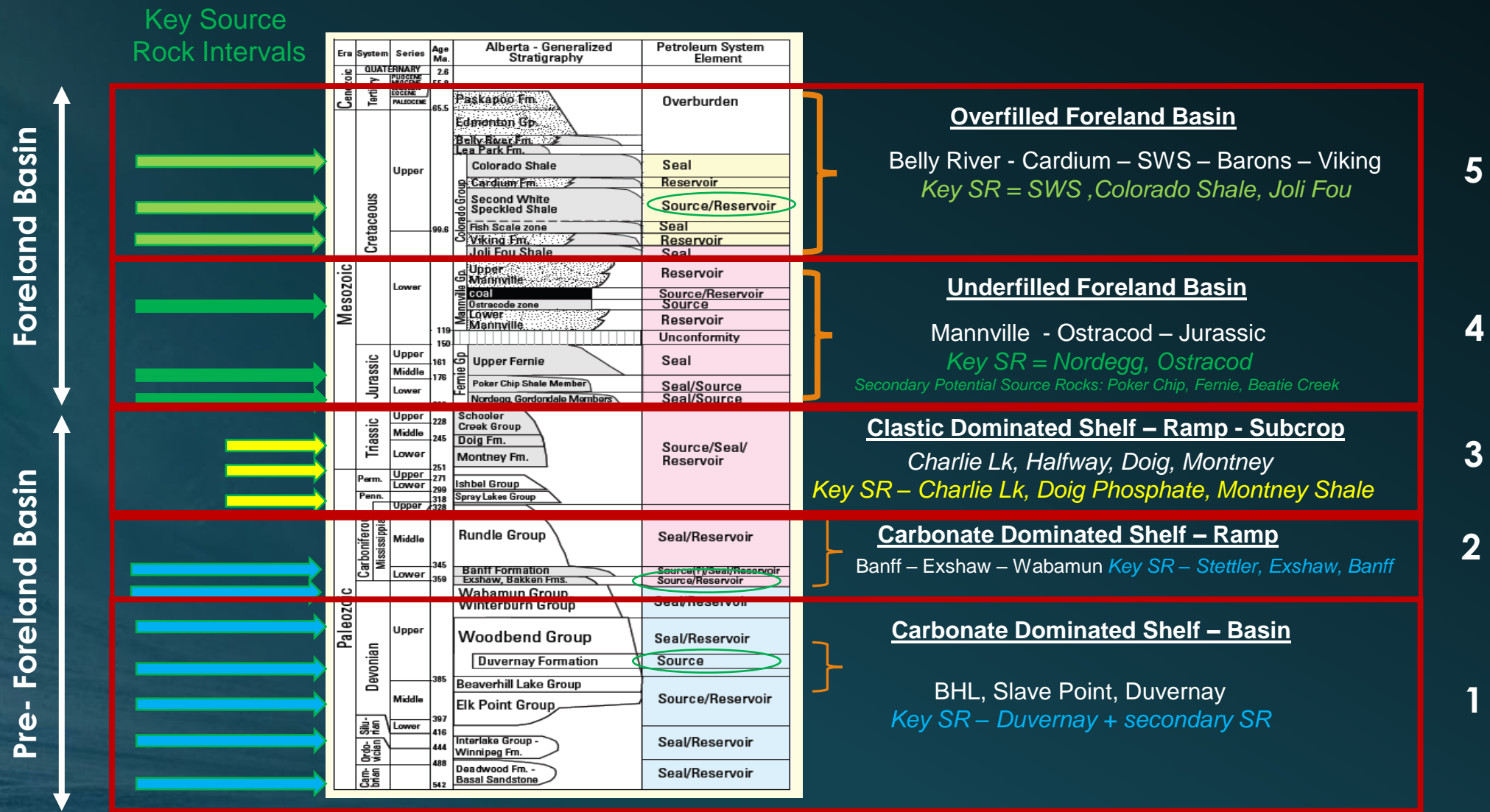
- Pardonet
- Baldonnel
- Doig Phosphate
- Montney
- Banff
- Exshaw
- Calmar/Ireton
- Duvernay
- Elk Point

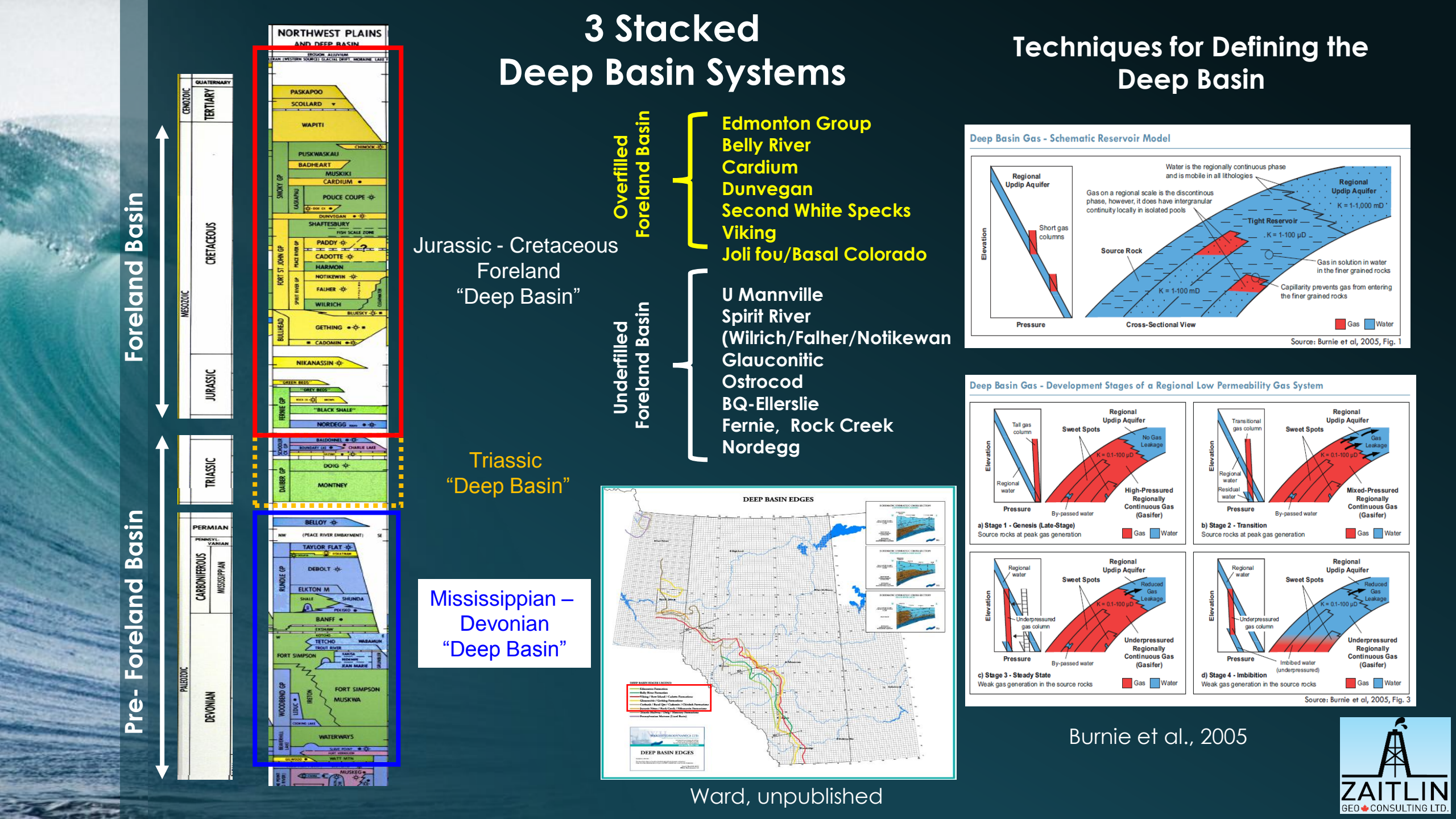
Foreland Basin

Pre- Foreland Basin



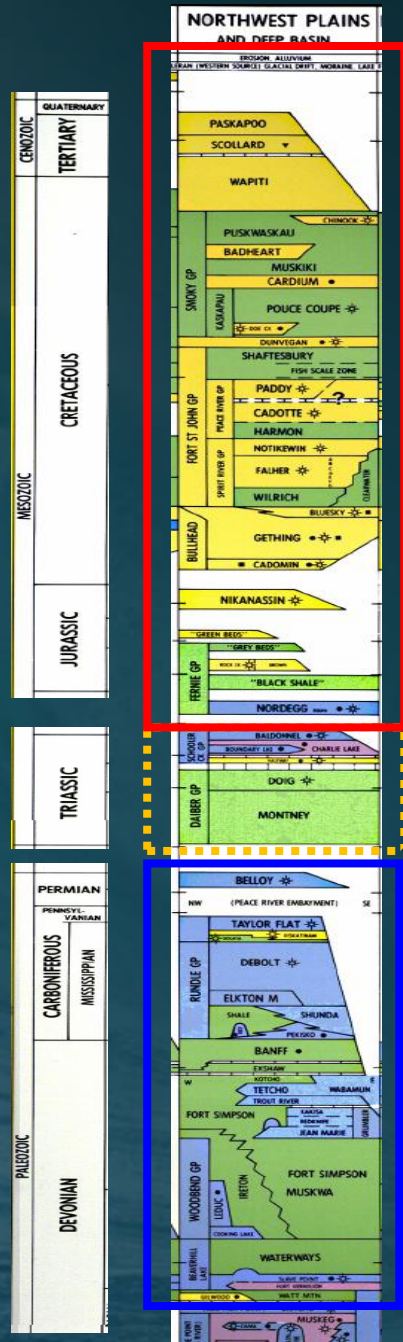
WCSB - Multiple Hydrocarbon Systems (5)





Foreland Basin

Pre- Foreland Basin



3 Stacked Deep Basin Systems

Jurassic - Cretaceous
Foreland
"Deep Basin"

Triassic
"Deep Basin"

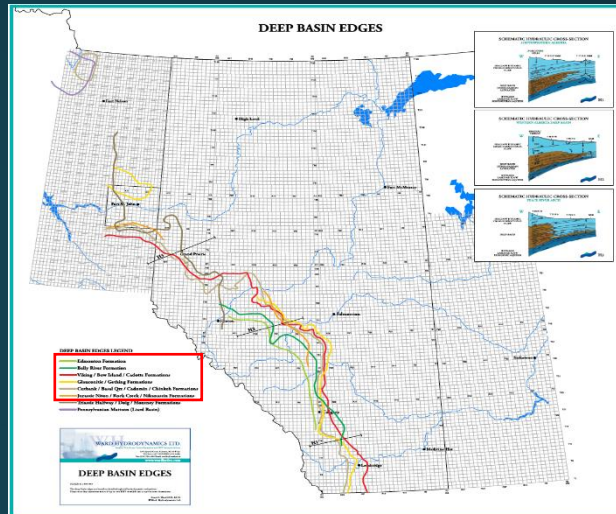
Mississippian –
Devonian
"Deep Basin"

Overfilled Foreland Basin

Underfilled Foreland Basin

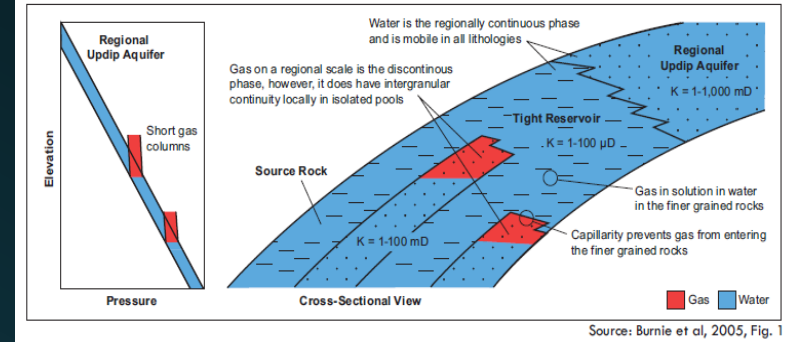
Edmonton Group
Belly River
Cardium
Dunvegan
Second White Specks
Viking
Joli fou/Basal Colorado

U Mannville
Spirit River
(Wilrich/Falher/Notikewan)
Glaucouitic
Ostrocod
BQ-Ellerslie
Ferne, Rock Creek
Nordegg

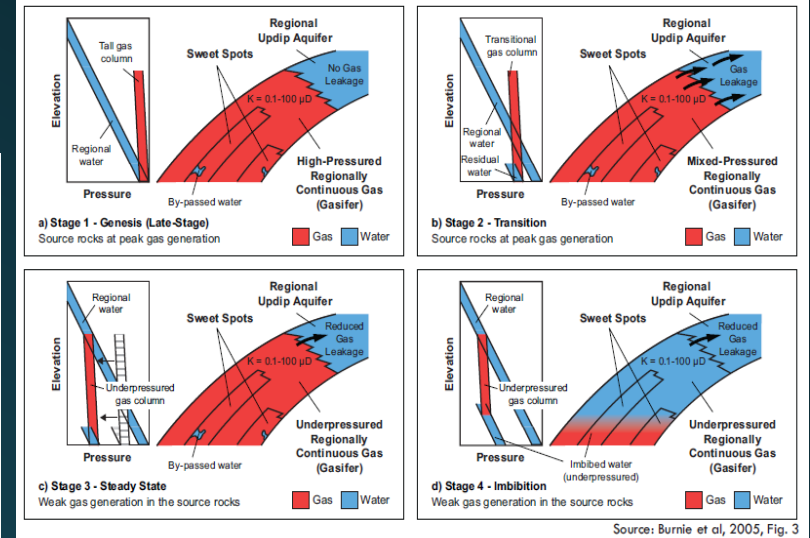


Techniques for Defining the Deep Basin

Deep Basin Gas - Schematic Reservoir Model



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



Burnie et al., 2005



Western Canada Sedimentary Basin (WCSB)

Foreland Basin

Pre-Foreland Basin

Era	System	Series	Age Ma.	Alberta - Generalized Stratigraphy	Petroleum System Element			
Cenozoic	Tertiary	Pliocene	2.6					
			55.8					
Cretaceous	Upper	Colorado Group	65.5	Paskapoo Fm.	Overburden			
				Edmonton Gp.				
				Belly River Fm.				
				Lea Park Fm.				
				Colorado Shale	Seal			
				Cardium Fm.	Reservoir			
				Second White Speckled Shale	Source/Reservoir			
				Fish Scale zone	Seal			
				Viking Fm.	Reservoir			
				Joli Fou Shale	Seal			
			Mesozoic	Lower	Mannville Gp.	119	Upper Mannville	Reservoir
							coal	Source/Reservoir
	Ostracode zone	Source						
	Lower Mannville	Reservoir						
150	Unconformity							
Jurassic	Upper	Fernie Gp.				161	Upper Fernie	Seal
						176	Poker Chip Shale Member	Seal/Source
							Nordegg, Gordondale Members	Seal/Source
Triassic	Upper					228	Schooler Creek Group	
			245	Doig Fm.				
				Montney Fm.	Source/Seal/Reservoir			
			251					
Paleozoic	Carboniferous	Mississippian	271	Ishbel Group				
			299	Spray Lakes Group				
			318					
			328					
				Rundle Group	Seal/Reservoir			
			345	Banff Formation	Source(?)Seal/Reservoir			
			359	Exshaw, Bakken Fms.	Source/Reservoir			
				Wabamun Group, Winterburn Group	Seal/Reservoir			
			Devonian	Upper			Woodbend Group	Seal/Reservoir
							Duvernay Formation	Source
385	Beaverhill Lake Group							
	Elk Point Group	Source/Reservoir						
397								
416	Interlake Group - Winnipeg Fm.	Seal/Reservoir						
Cambrian-Ordovician	Lower		444	Deadwood Fm. - Basal Sandstone	Seal/Reservoir			
			488					
			542					

Foreland Basin

Overfilled Foreland Basin

Underfilled 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

Accommodation Cycles

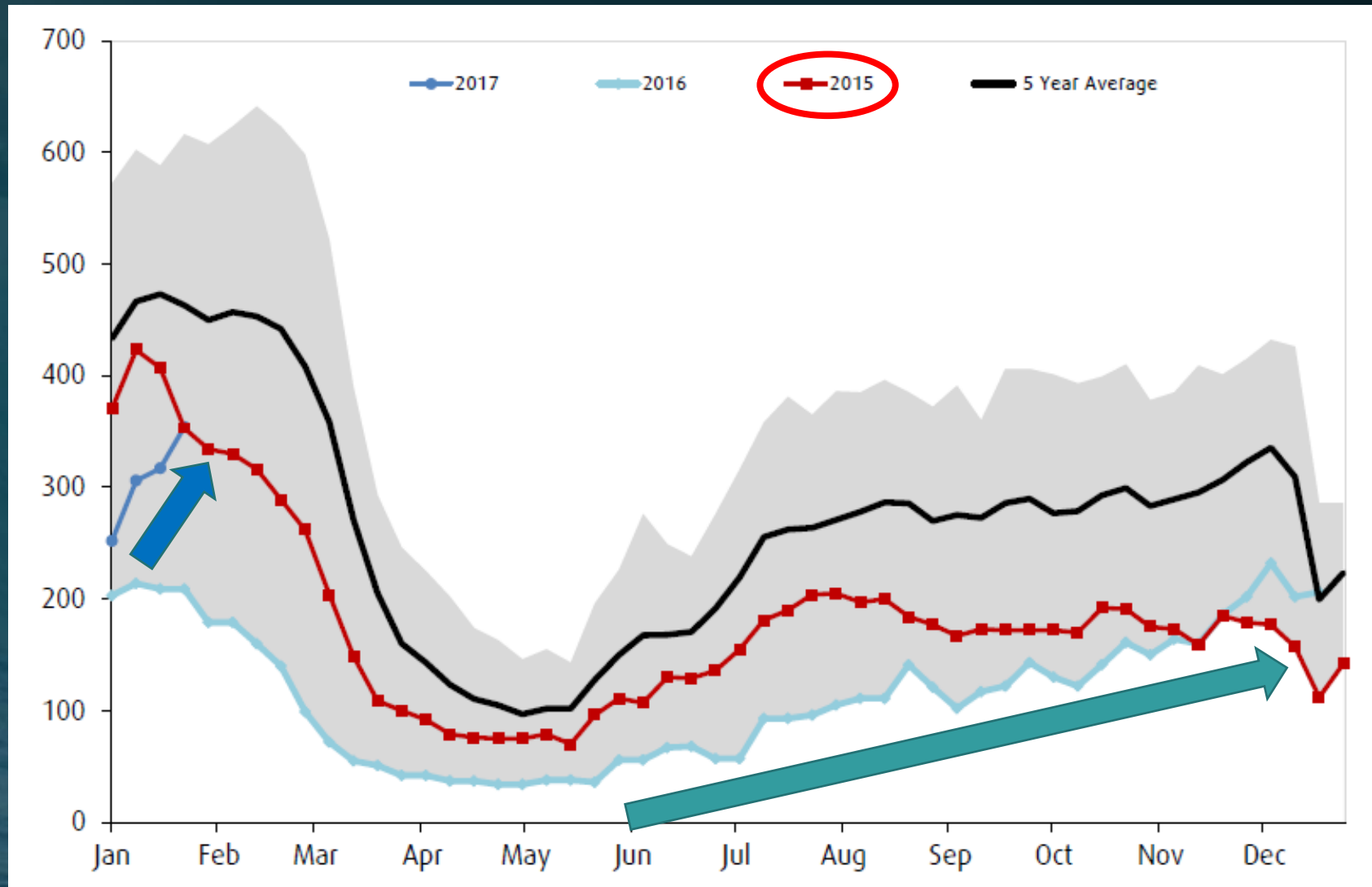


Pre-Foreland Basin

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



WCSB Drilling Activity - Rig Count



- 5 Year Average
- 2015 vs. 2016 activity
- Increase mid 2016 into 2017
- Top Plays based on activity:
 - Viking
 - Spirit River Group
 - Montney
 - Duvernay

Top Wells - 2015 Drilling Activity

*BMO Oil and Gas: E&P – Canada Report
Top Wells – Alberta (January-December 2015)*

- **Top 40 wells (one-month, three-month and twelve-month cumulative basis) organized:**
 - 20 best oil/condensate rate and 20 best raw natural gas rate
 - bbl/d, mmcf/d and boe/d (calendar day rate)
 - Location, Producing formation, Spud and On Production Date, TVD, bbl/d, mmcf/d, boe/d, % oil, % gas
- **Caveat:**
 - *Useful screening tool; however these are just rates, and aren't necessarily indicative of:*
 - *relative economics, including IRRs, NPVs, payouts, etc. and*
 - *returns from a corporate perspective*
- **This study then took BMO data, re-classified by:**



- **Overfilled Foreland Basin**
- **Underfilled Foreland Basin**
- **Pre-foreland Basin**

Disorganized



Organized



Top 2015 Drilling Activity

Last 12 Months Top 20 Monthly *Oil/Condensate* Wells (Calendar Day Rate)

4 wells - Deep Basin – Overfilled Foreland Basin – (1 *Belly River* and 3 *Dunvegan*)

1 well - Deep Basin – Underfilled Foreland Basin – (1 *Gething*)

15 wells - Deep Basin - Pre-foreland Basin – (Doig, Montney, Bakken, Swan Hills, Halfway, Dulwood, Charlie Lake)

Exhibit 6: Last 12 Months Top Oil/Condensate Wells by Operator (Calendar Day Rate)

Unique Well ID	Current Operator Name	Formation	Spud Date	On Prod	Field Name	Pool Name	TVD (m)	Peak Mthly boe/d	Cum. Oil & Cond. (bbl)	Cum. Gas (mcf)	% oil
102/15-06-075-08W6/00	Surge Enrg Inc	TRdoig	6/27/2015	2015/07	VALHALLA	TD UND	1,990	2,613	194,985	483,762	71%
100/04-06-075-08W6/00	Surge Enrg Inc	TRdoig	3/18/2015	2015/04	VALHALLA	DOIG V	2,002	2,495	175,579	542,089	66%
100/09-35-066-24W5/00	RMP Enrg Inc	TRmontney	1/13/2015	2015/02	ANTE CREEK NORTH	TRIASSIC E	1,920	1,488	125,031	888,564	46%
102/04-15-047-15W5/00	Boulder Enrg Ltd	Kbelly_rv	1/3/2015	2015/02	BRAZEAU RIVER	BELLY RIVER P6P	1,925	901	123,177	269,504	73%
100/13-36-066-24W5/00	RMP Enrg Inc	TRmontney	1/30/2015	2015/02	ANTE CREEK NORTH	TRIASSIC E	1,954	1,206	110,373	440,907	60%
102/09-19-003-16W4/00	Granite Oil Corp	Mbakken	2/26/2015	2015/03	FERGUSON	TD UND	1,283	404	88,996	110,134	83%
100/07-03-068-08W5/00	Aspenleaf Enrg Ltd	Dswan_hl	12/1/2014	2015/02	SWAN HILLS	COMMINGLED POOL 001	2,337	341	84,505	62,714	89%
100/12-27-060-23W5/00	Delphi Enrg Corp	TRmontney	12/7/2014	2015/02	BIGSTONE	MONT UND	2,668	1,462	81,175	1,159,541	30%
102/15-13-062-07W6/00	Jupiter Rsrcs Inc	Kdunvegan	10/24/2014	2015/03	KAKWA	DUNVEGAN CC	2,699	617	80,003	295,205	62%
100/01-24-003-17W4/00	Granite Oil Corp	Mbakken	1/7/2015	2015/02	FERGUSON	WR BANFF-EXSHAW-BV	1,303	414	76,367	186,718	71%
100/11-31-064-18W5/00	Trilogy Rsrcs Ltd	TRmontney	2/9/2015	2015/07	KAYBOB	TRIASSIC B	1,790	1,185	75,569	630,638	42%
100/03-10-077-09W6/00	Birchcliff Enrg Ltd	TRhalfway	12/30/2014	2015/02	PROGRESS	HALFWAY C	1,919	556	70,915	142,756	75%
100/14-18-062-25W5/00	Whitecap Rsrcs Inc	Kdunvegan	1/7/2015	2015/02	SIMONETTE	DUNVEGAN F	1,977	565	68,504	343,838	54%
100/13-13-062-07W6/00	Jupiter Rsrcs Inc	Kdunvegan	12/6/2014	2015/02	KAKWA	DUNVEGAN CC	2,706	601	67,886	286,431	59%
100/13-34-066-24W5/00	RMP Enrg Inc	TRmontney	7/15/2015	2015/08	ANTE CREEK NORTH	TRIASSIC E	1,936	1,437	67,689	408,018	50%
100/03-20-063-19W5/00	Trilogy Rsrcs Ltd	Kgething	1/9/2015	2015/07	KAYBOB	GETHING O	1,826	1,148	66,660	611,102	40%
100/12-36-086-13W5/00	Arsenal Enrg Inc	Dgilwood	12/2/2014	2015/02	EVI	GILWOOD AAA	1,590	209	64,683	13,658	97%
100/04-10-077-09W6/00	Birchcliff Enrg Ltd	TRhalfway	12/3/2014	2015/02	PROGRESS	HALFWAY FF	1,923	533	64,554	70,523	85%
100/07-15-077-07W6/00	Exshaw Oil Corp	TRchly_ik	12/5/2014	2015/02	VALHALLA	CHARLIE LAKE F3F	1,598	497	64,416	324,881	54%
100/13-36-081-13W6/00	Glenogle Enrg Inc	TRdoig	11/16/2014	2015/02	DOE	COMMINGLED POOL 001	1,576	382	63,576	302,644	56%

Source: geoSCOUT, BMO Capital Markets.

Top 2015 Drilling Activity

Last 12 Months Top 20 Monthly **Gas Wells** (Calendar Day Rate)

0 wells - Deep Basin – Overfilled Foreland Basin

20 wells - Deep Basin – Underfilled Foreland Basin – **Spirit River Group**

0 wells - Deep Basin - Pre-foreland Basin

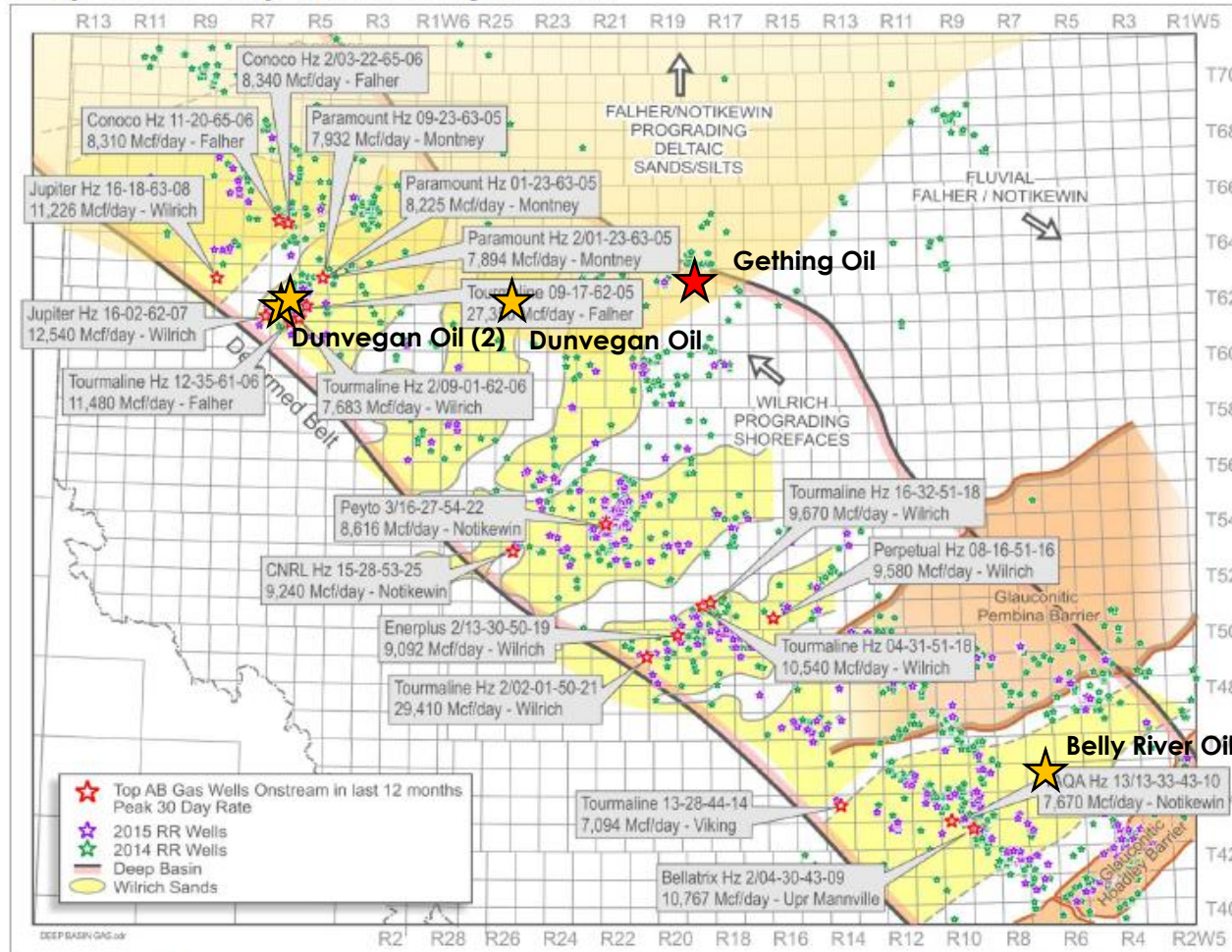
Exhibit 7: Last 12 Months Top Gas Wells by Operator (Calendar Day Rate)

Unique Well ID	Current Operator Name	Formation	Soud Date	On Prod	Field Name	Pool Name	TVD (m)	Peak Mthly boe/d	Cum. Oil & Cond. (bbl)	Cum. Gas (mcf)	% oil
100/16-18-063-08W6/00	Jupiter Rsrcs Inc	Kwilrich	6/4/2014	2015/02	KAKWA	COMMINGLED POOL 040	3,262	2,090	1	2,836,576	0%
100/16-02-062-07W6/00	Jupiter Rsrcs Inc	Kwilrich	1/1/2015	2015/03	KAKWA	WILR UND	3,237	2,338	428	2,820,721	0%
100/09-17-062-05W6/00	Tourmaline Oil Corp	Kfalher	2/16/2015	2015/06	KAKWA	SPRT R UND	2,929	3,456	147	2,453,049	0%
102/16-31-062-05W6/00	ConocoPhillips Cda Oprtns	Kfalher	9/2/2014	2015/02	KAKWA	COMMINGLED POOL 005	2,920	1,678	166	2,283,911	0%
100/09-32-053-23W5/00	Peyto Expl&Dvlp Corp	Kspirit_r	1/5/2015	2015/02	SUNDANCE	COMMINGLED POOL 034	3,222	1,871	54	2,216,065	0%
100/13-22-054-25W5/00	Tourmaline Oil Corp	Knotikwn	7/30/2015	2015/09	MARSH	NOTI UND	3,272	3,369	7,263	2,206,478	2%
100/11-20-065-06W6/00	ConocoPhillips Cda Oprtns	Kfalher	1/2/2014	2015/02	WAPITI	COMMINGLED MFP9529	2,459	1,384	17	2,174,778	0%
100/08-16-051-16W5/00	Perpetual Enrg Operating	Kwilrich	12/10/2014	2015/02	EDSON	UPPER MANNVILLE QQ	2,670	1,625	2,672	2,167,488	1%
100/07-30-056-24W5/00	Tourmaline Oil Corp	Knotikwn	7/3/2015	2015/08	WILD RIVER	NOTI UND	2,798	2,958	2,023	2,036,647	1%
100/12-06-050-20W5/00	Tourmaline Oil Corp	Kwilrich	6/7/2015	2015/08	MINEHEAD	TD UND	3,349	2,814	216	2,013,282	0%
102/03-22-065-06W6/00	ConocoPhillips Cda Oprtns	Kfalher	1/29/2014	2015/02	WAPITI	COMMINGLED MFP9529	2,460	1,390	0	1,995,975	0%
100/13-12-062-06W6/00	Tourmaline Oil Corp	Kwilrich	11/17/2014	2015/03	KAKWA	SPRT R UND	3,078	2,685	1,422	1,991,471	0%
100/09-10-050-20W5/00	Husky Oil Oprtns Ltd	Kwilrich	1/8/2015	2015/03	ANSELL	UPPER MANNVILLE ZZ	3,136	1,195	0	1,975,648	0%
100/13-29-043-10W5/00	TAQA North Ltd	Knotikwn	9/7/2014	2015/02	FERRIER	UPPER MANNVILLE III	2,590	1,118	6	1,947,906	0%
100/15-28-053-25W5/02	Cdn Nat Rsrcs Ltd	Knotikwn	1/24/2015	2015/04	MARSH	TD UND	3,444	1,540	230	1,940,978	0%
102/13-30-050-19W5/00	Enerplus Corp	Kwilrich	12/2/2014	2015/04	ANSELL	COMMINGLED MFP9529	3,090	1,515	86	1,888,021	0%
100/01-28-043-12W5/00	Peyto Expl&Dvlp Corp	Kfalher	1/4/2015	2015/02	BRAZEAU RIVER	COMMINGLED POOL 028	2,969	1,498	21	1,760,063	0%
102/16-12-058-27W5/02	Tourmaline Oil Corp	Kwilrich	10/18/2014	2015/02	LELAND	U MANN UND	3,043	1,623	1,731	1,734,965	1%
102/15-19-045-11W5/00	Westbrick Enrg Ltd	Kfalher	2/12/2015	2015/03	PEMBINA	UNDEFINED POOL	2,582	1,593	1,011	1,730,972	0%
100/16-13-044-11W5/00	TAQA North Ltd	Kmannvl	7/19/2014	2015/05	FERRIER	COMMINGLED MFP9537	2,554	1,438	0	1,700,092	0%

Source: geoSCOUT, BMO Capital Markets.

Top 2015 Drilling Activity Distribution of Top AB Gas Wells (based on IP 30)

Deep Basin – Top Well Activity in 2015



- Top 20/20 gas wells
- Spirit River Reservoir Trends (yellow)
- Underfilled FB

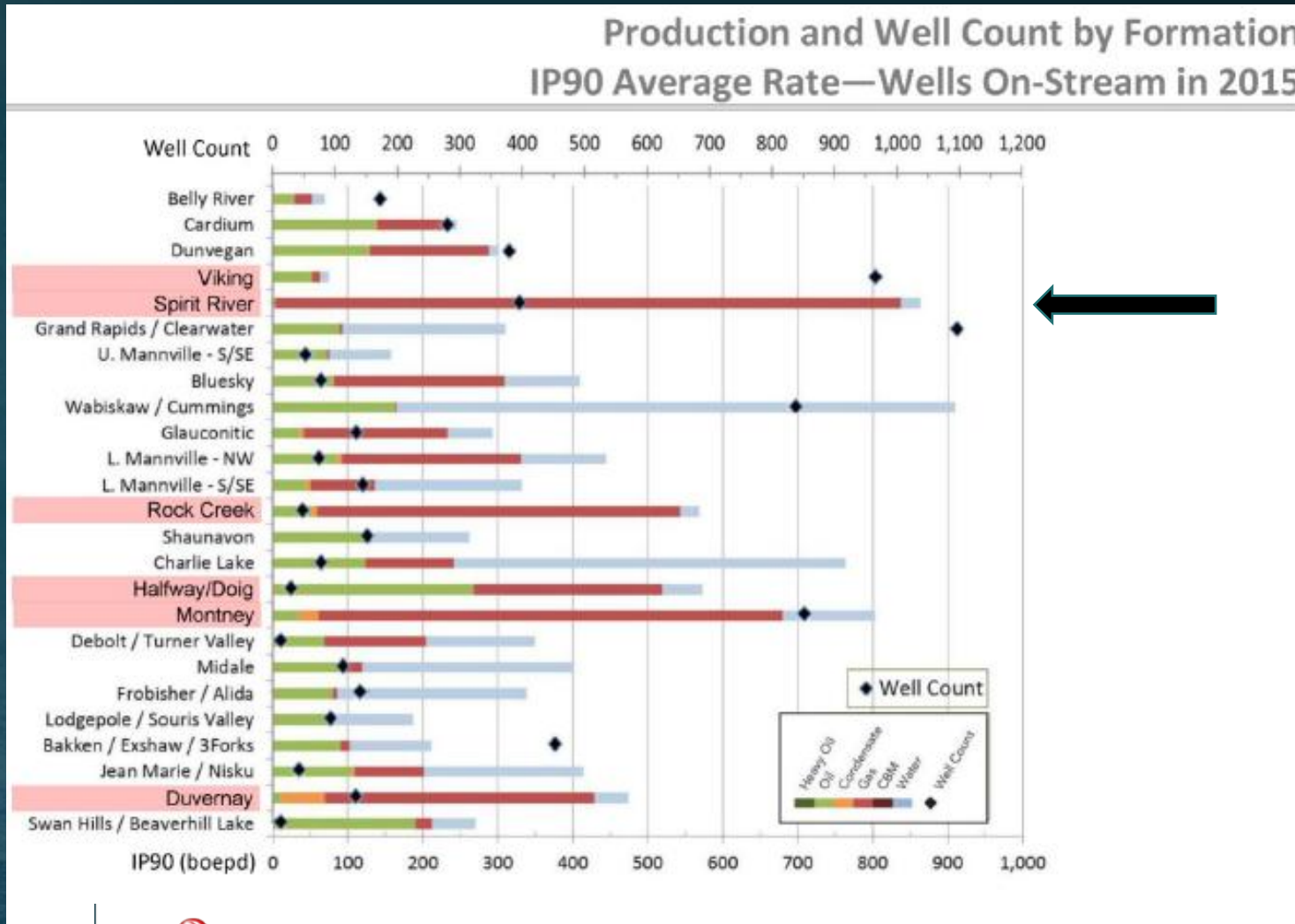
5/20 Top Oil Wells

- ★ Overfilled FB
- ★ Underfilled FB

C. Stephens,
CSUR Luncheon
Presentation, 2016

(1): Scotiabank Geoscout, September 2015

Production and Well Count IP90 Average Rate – Wells on Stream in 2016



Foreland Basin

Pre-Foreland Basin

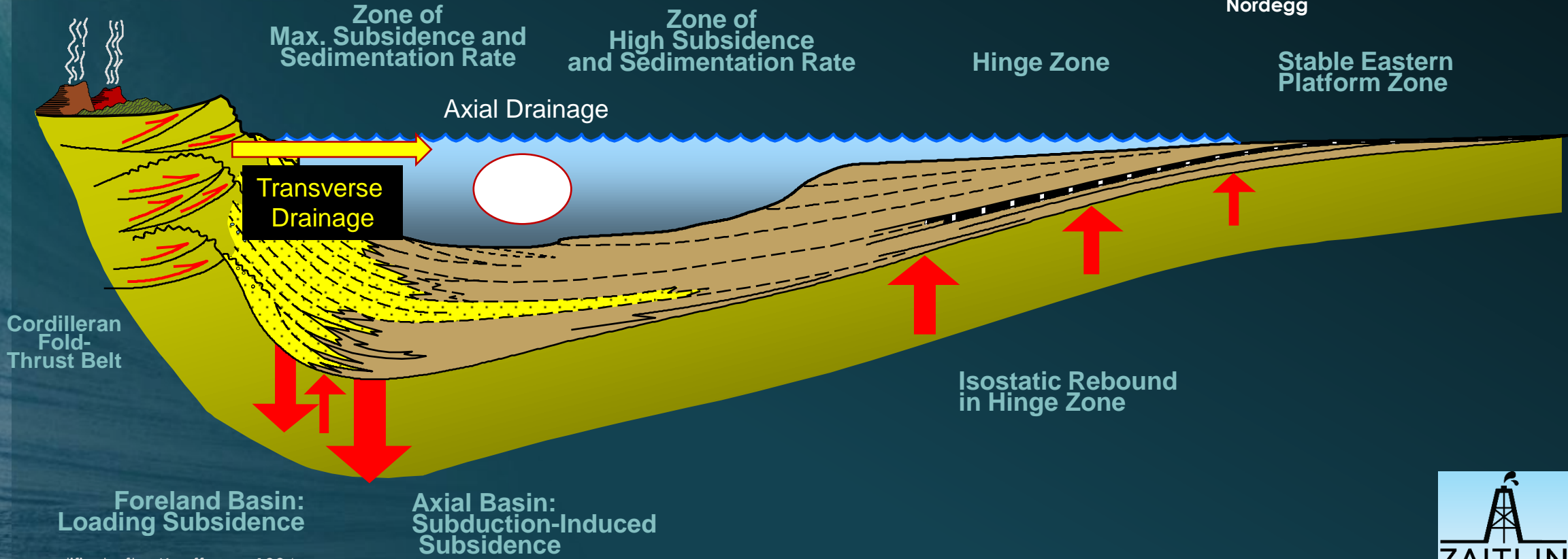
- Viking
 - N ~960 wells
 - IP90 ~ 90boepd
- Spirit River
 - N ~ 390 wells
 - IP90 ~ 850 boepd
- Montney
 - N ~ 840 wells
 - IP90 ~ 800 boepd
- Duvernay
 - N ~ 140
 - IP ~ 475boepd

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
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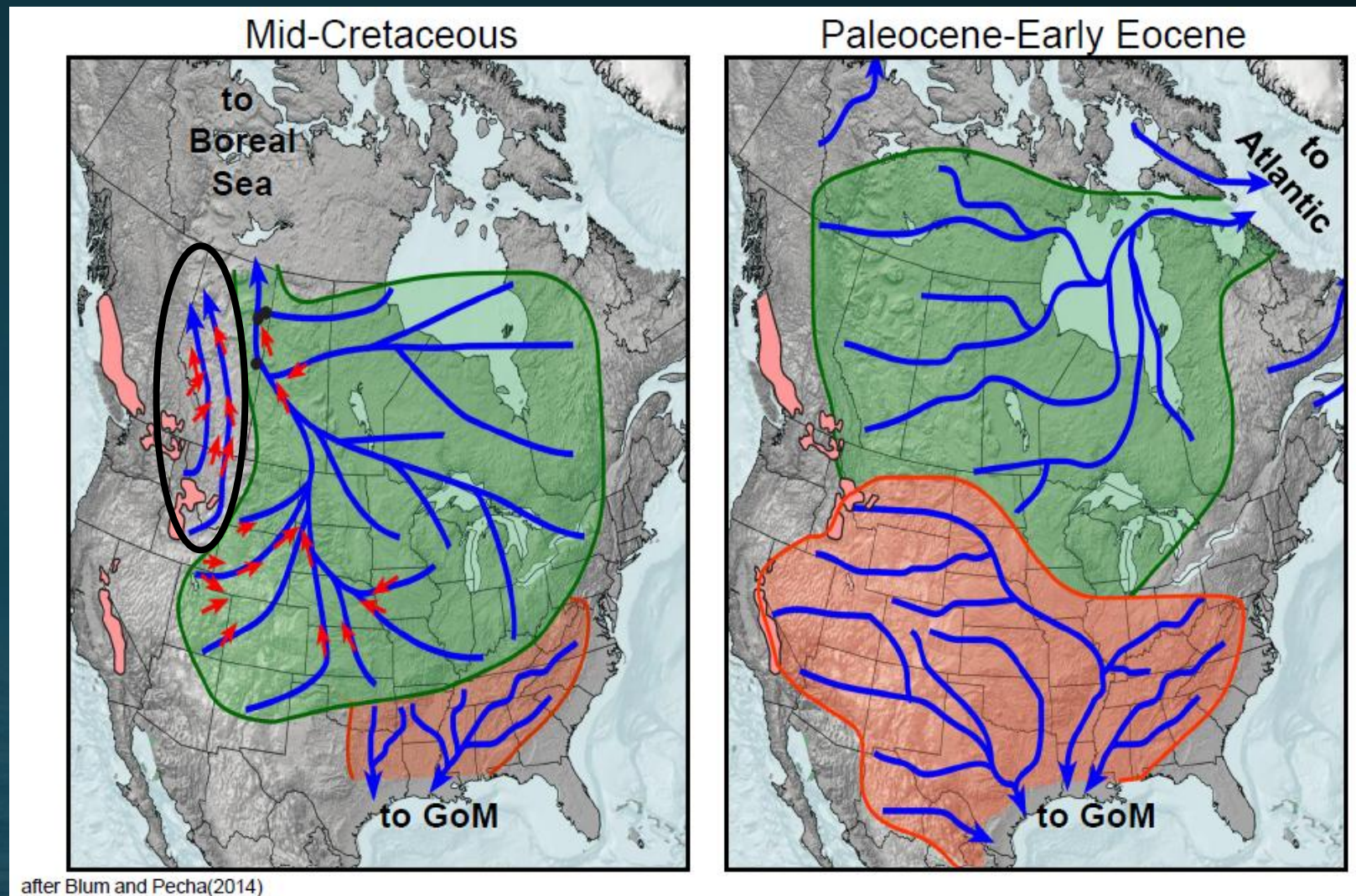


modified after Kauffman, 1984



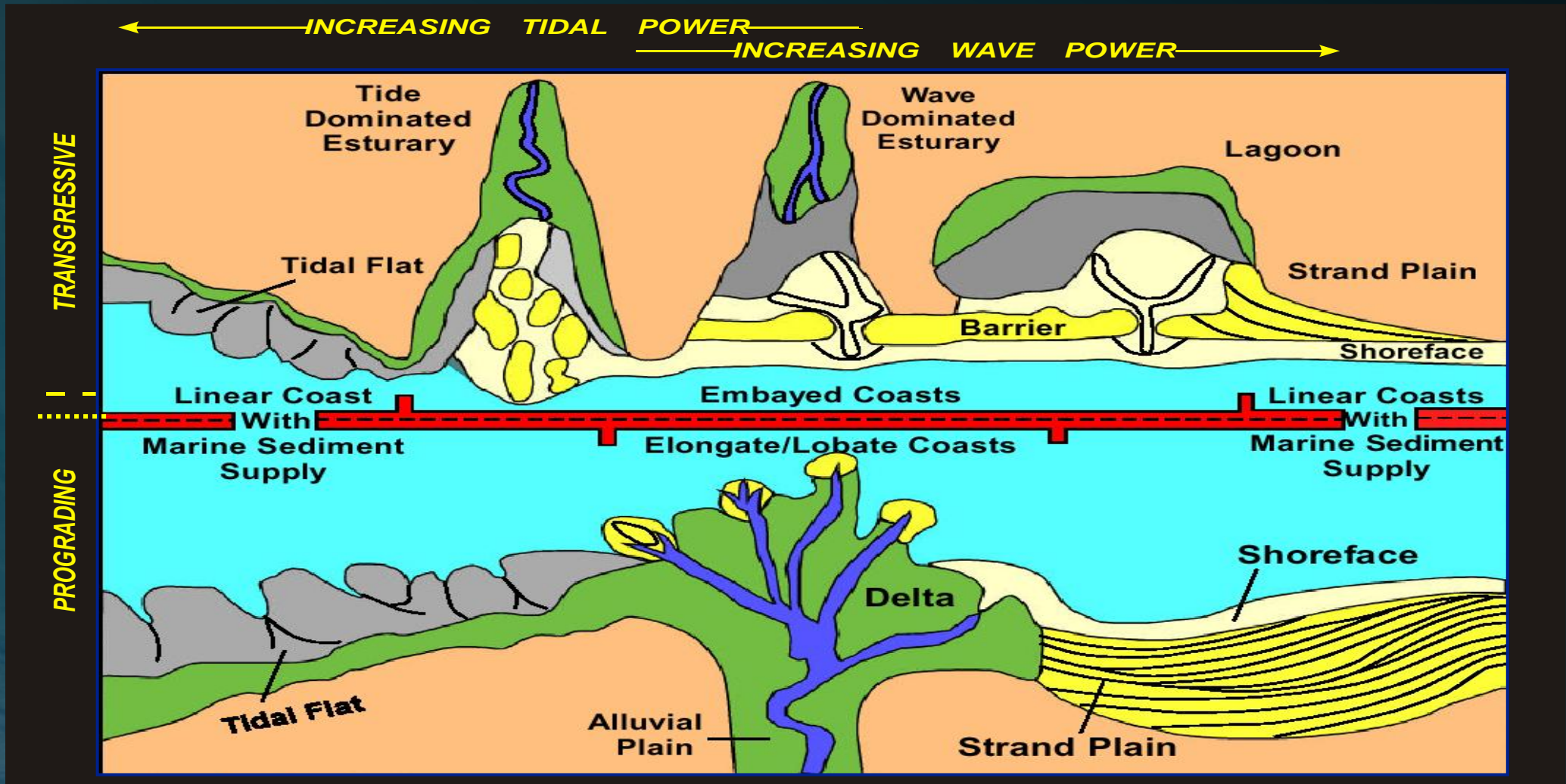
Continental Scale Paleodrainage Reorganization

Underfilled
Foreland Basin
Drainage to north



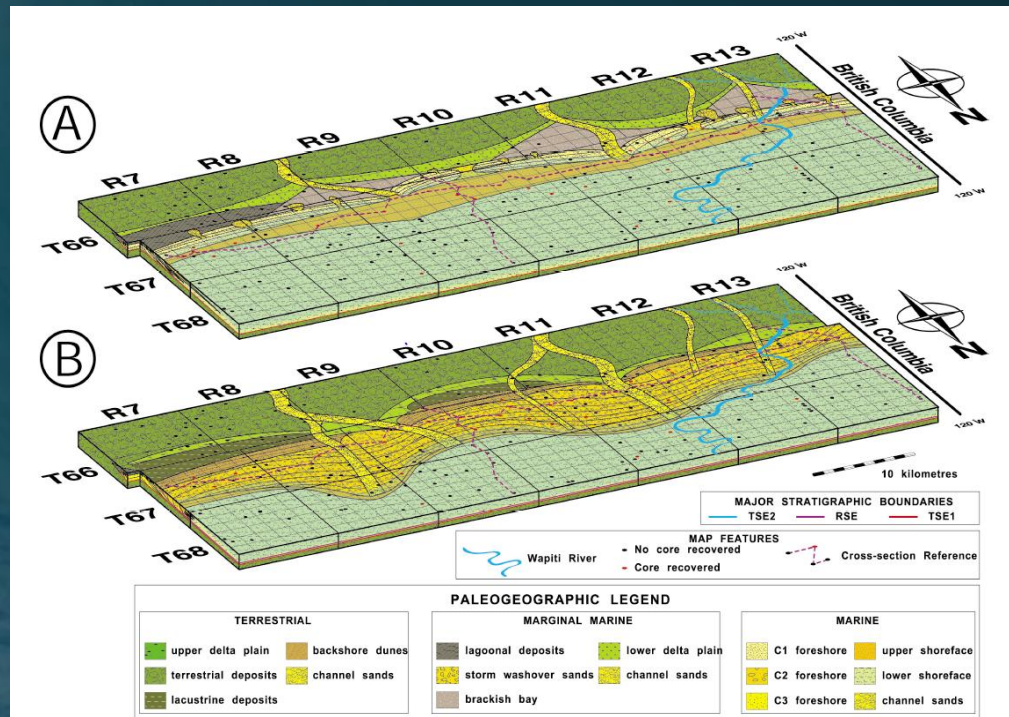
Blum et al., 2015

Coastal Classification – along strike variation



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)

Delta Models

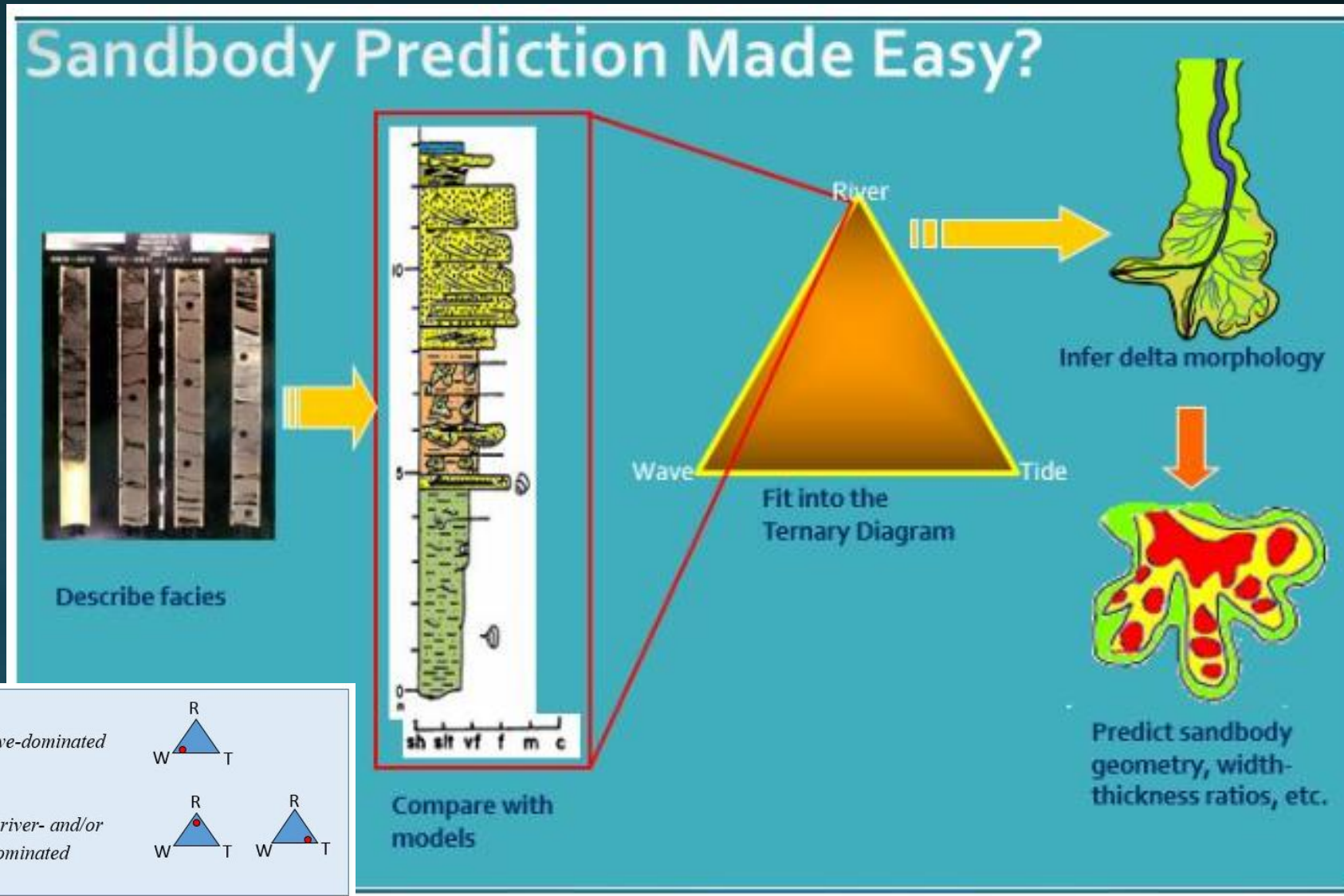
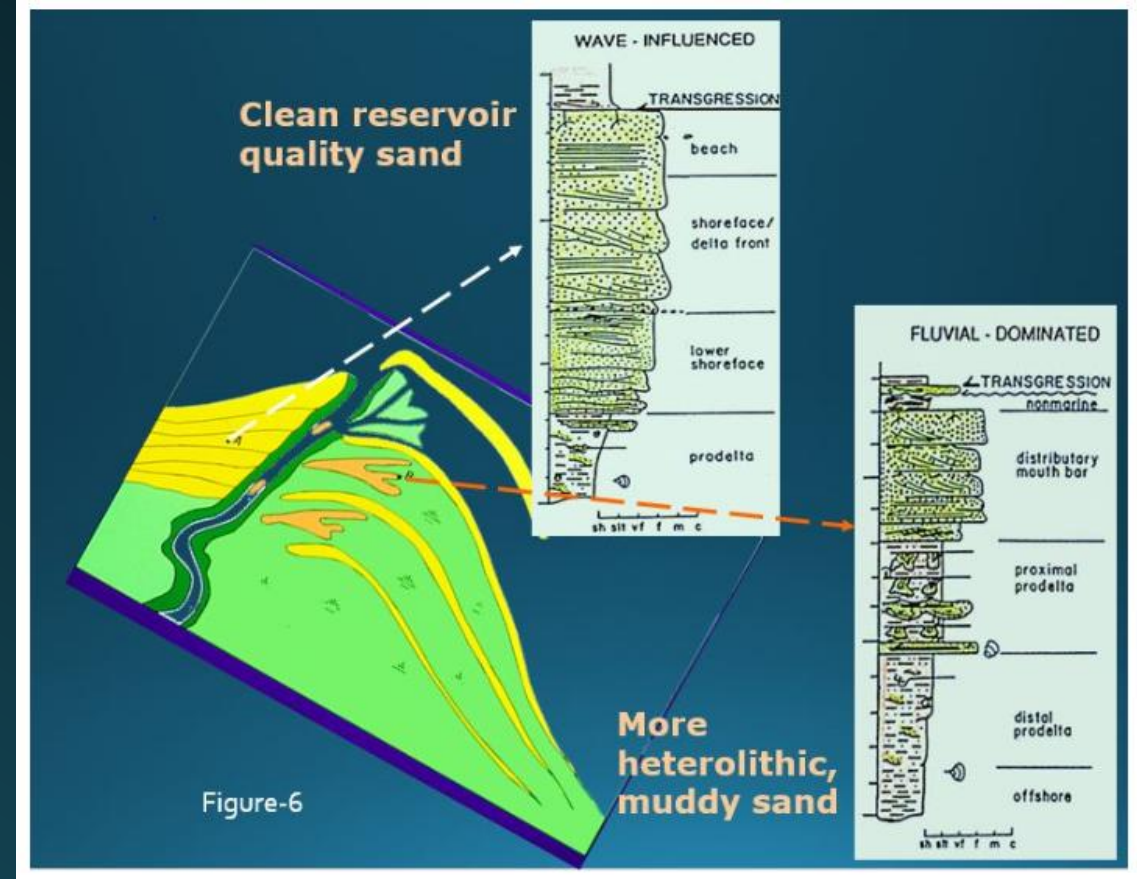
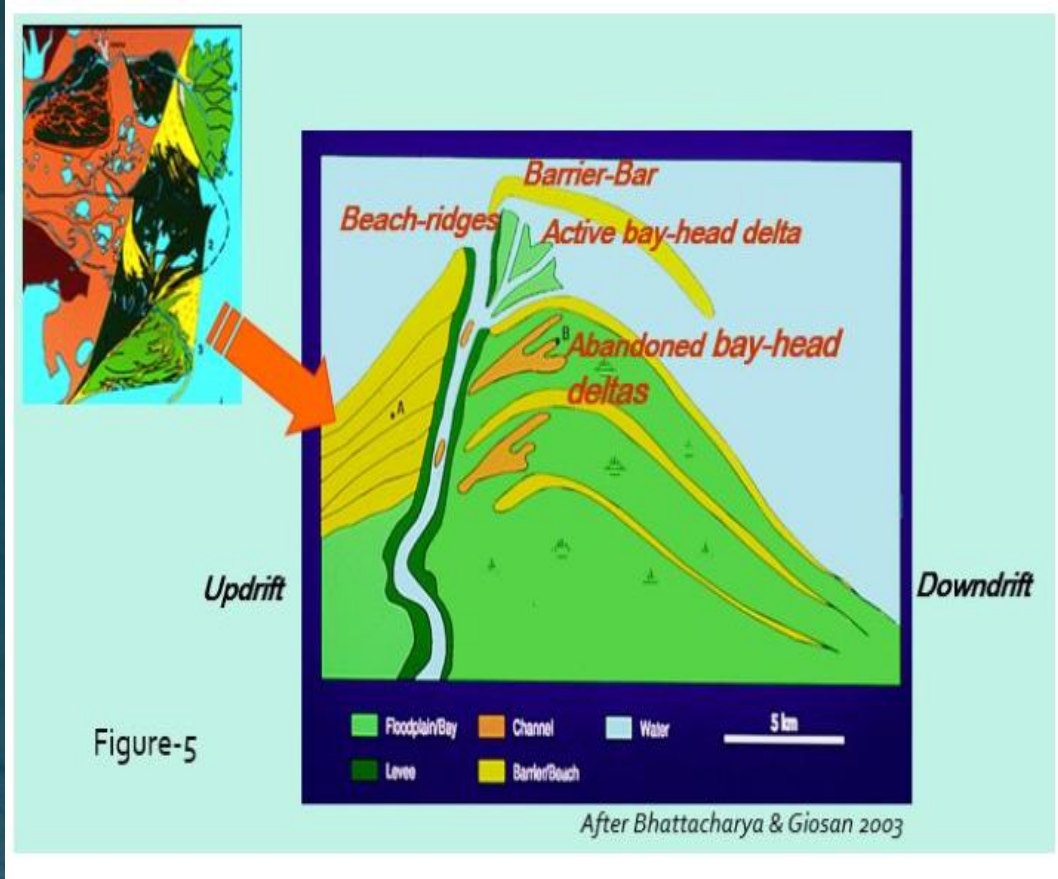


Figure-7

Updrift : wave-dominated

Downdrift : river- and/or tide-dominated

Asymmetric Wave-Influenced Delta Model



Western Canada Sedimentary Basin Underfilled Foreland Basin Examples

Era	System	Series	Age	Alberta - Generalized Stratigraphy	Petroleum System Element		
Cenozoic	Quaternary	QUATERNARY	2.6				
		Tertiary	PLIOCENE	55.8	Paskapoo Fm.	Overburden	
			MIOCENE		Edmonton Gp.		
	Mesozoic	Cretaceous	Upper	65.5	Belly River Fm.		Seal
				65.5	Lea Park Fm.		
				65.5	Colorado Shale		
			Lower	99.6	Cardium Fm.	Reservoir	
				99.6	Second White Speckled Shale	Source/Reservoir	
				99.6	Fish Scale zone	Seal	
		Jurassic	Lower	99.6	Viking Fm.	Reservoir	
				99.6	Joli Fou Shale	Seal	
				119	Upper Mannville	Reservoir	
				119	coal	Source/Reservoir	
				119	Ostracode zone	Source	
Paleozoic	Triassic	Upper	119	Mannville Gp.	Reservoir		
			119	Lower Mannville	Source/Reservoir		
		Middle	150	Unconformity	Unconformity		
			150	Upper Fernie	Seal		
	Permian	Upper	161	Poker Chip Shale Member	Seal/Source		
			178	Nordeg, Gordondale Members	Seal/Source		
		Lower	200	Schooner Creek Group	Source/Seal/Reservoir		
			228	Doig Fm.			
Carboniferous	Upper	245	Montney Fm.	Source/Seal/Reservoir			
		251	Ishbel Group				
	Middle	271	Spray Lakes Group	Seal/Reservoir			
		299	Rundle Group				
	Lower	318	Banff Formation	Source(?) / Seal / Reservoir			
		328	Exshaw, Bakken Fms.				
	Devonian	Upper	345	Wabamun Group, Winterburn Group	Seal/Reservoir		
			345	Woodbend Group			
			345	Duvernay Formation			
		Middle	359	Beaverhill Lake Group	Source/Reservoir		
385			Elk Point Group				
385			Interlake Group - Winnipeg Fm.				
Lower	397	Deadwood Fm. - Basal Sandstone	Seal/Reservoir				
	416						



- 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
- Nordeg

Accommodation Cycles

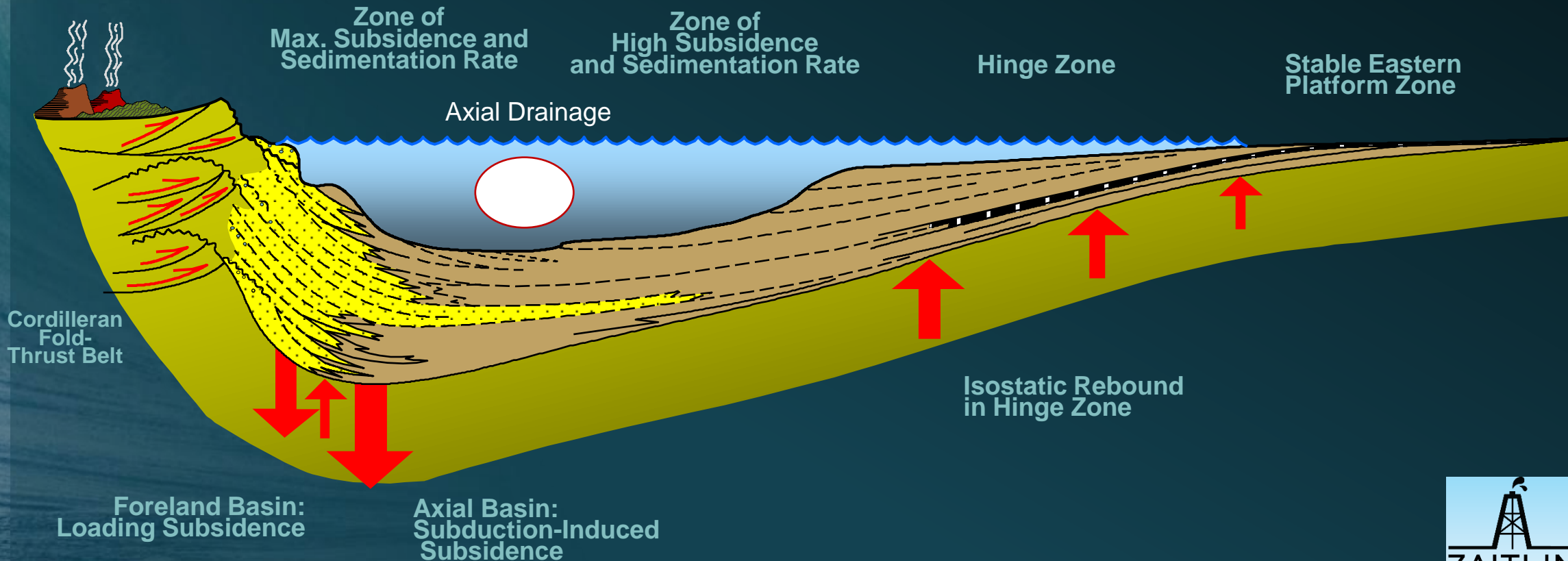
USGS Fact Sheet - Assessment of Undiscovered Conventional Oil and Gas Resources of the Western Canada Sedimentary Basin, Canada, 2012



Foreland Basin Axial Drainage vs. Transverse Drainage Underfilled FB

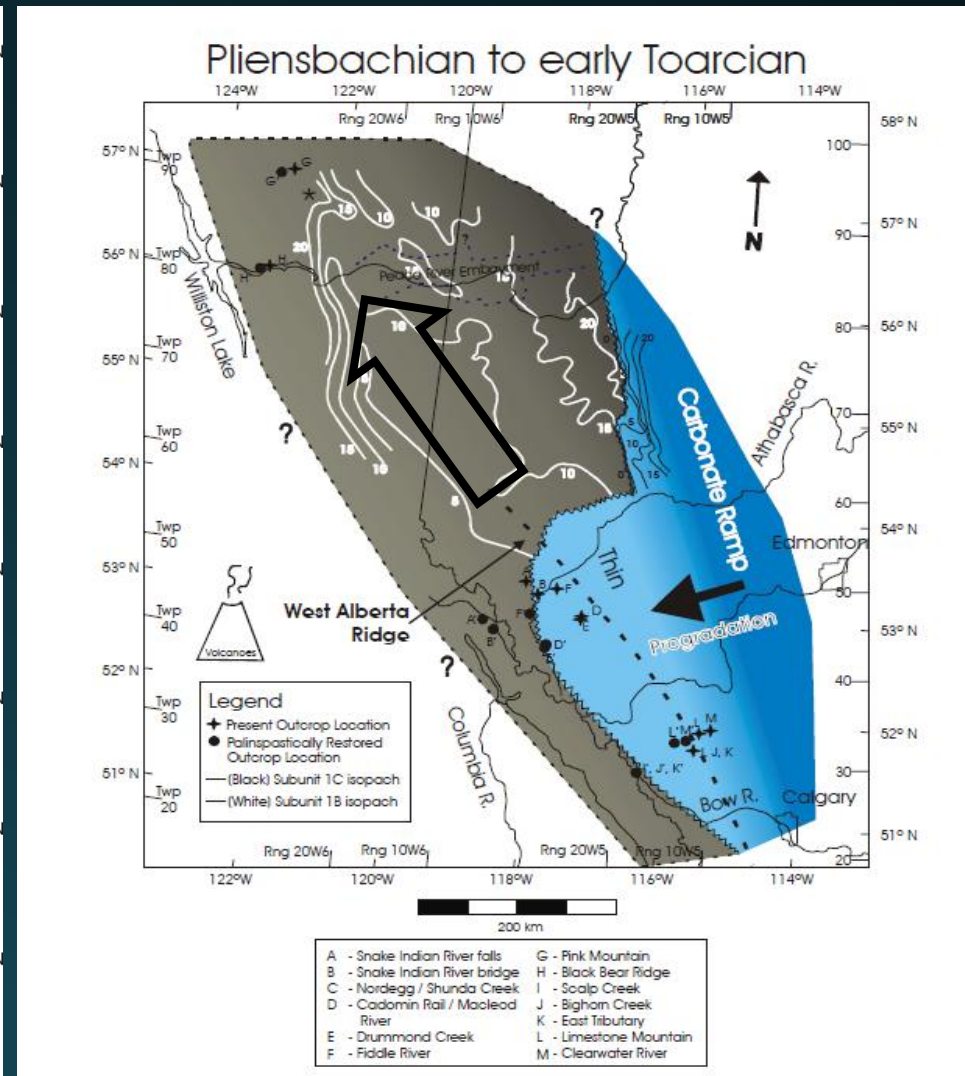
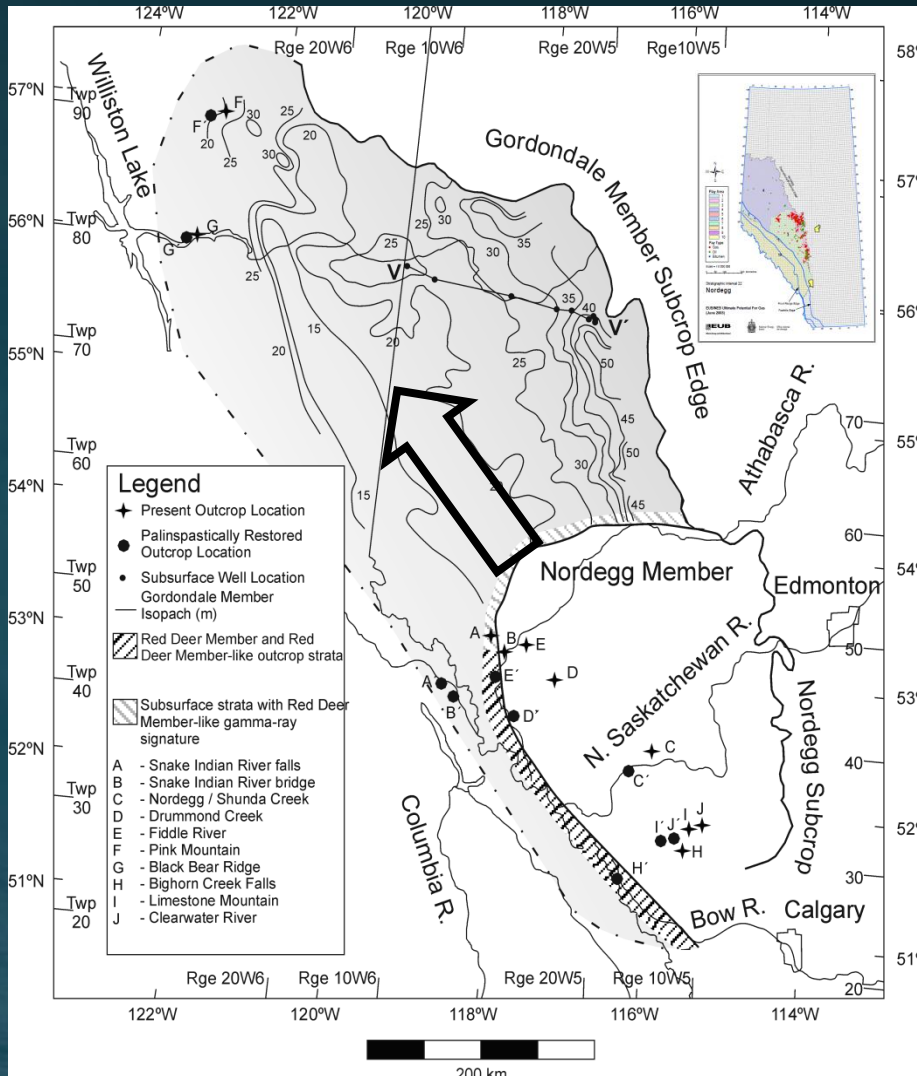
Underfilled
Foreland Basin

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



modified after Kauffman, 1984

Jurassic Nordegg FM - Foreland Basin

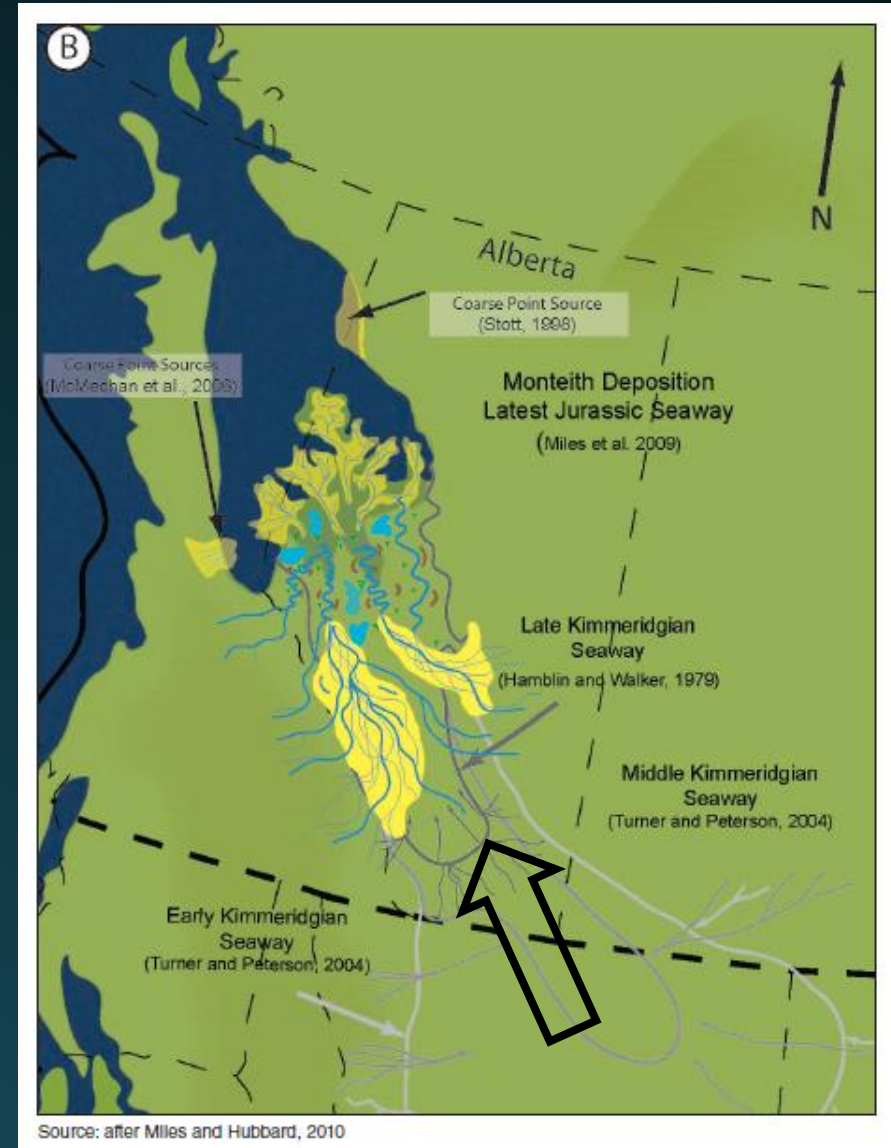
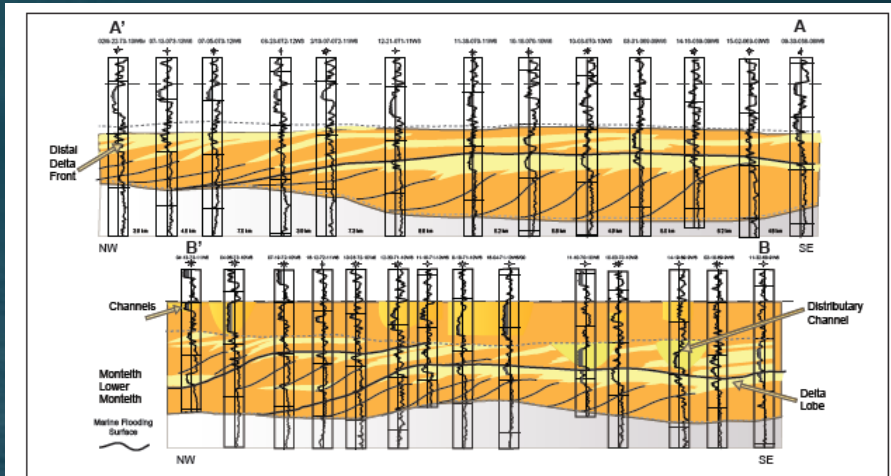
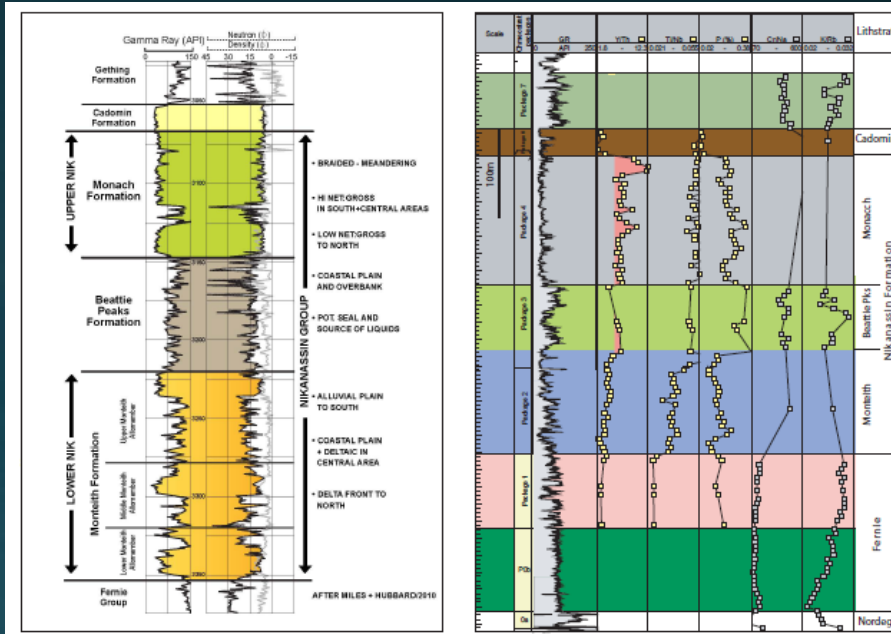


Asger – Deen Ph.D. Thesis



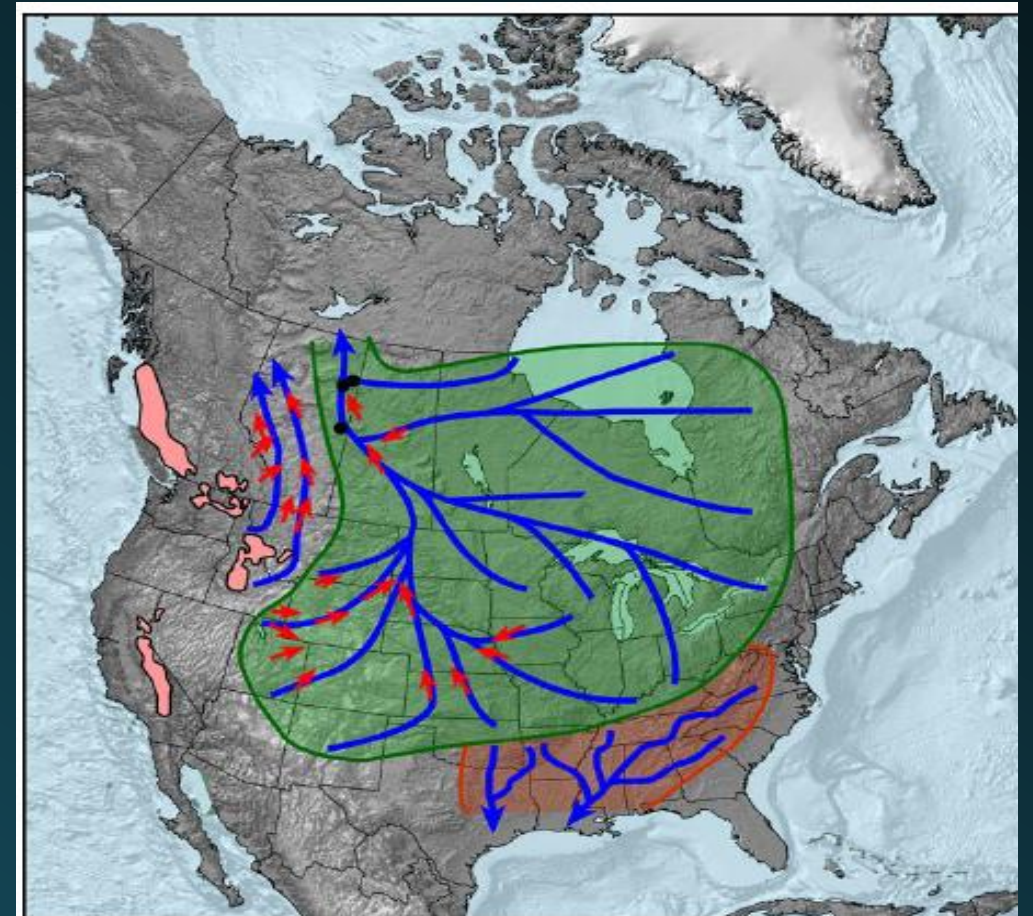
Axial Paleodrainage

Jurassic Nikinassin Fm



Axial Paleodrainage

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



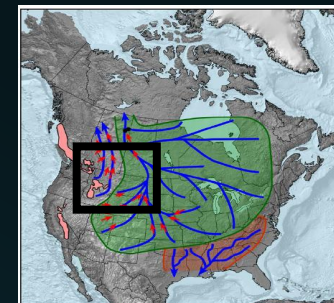
© Ron Blakey, 2013

Blum, 2015

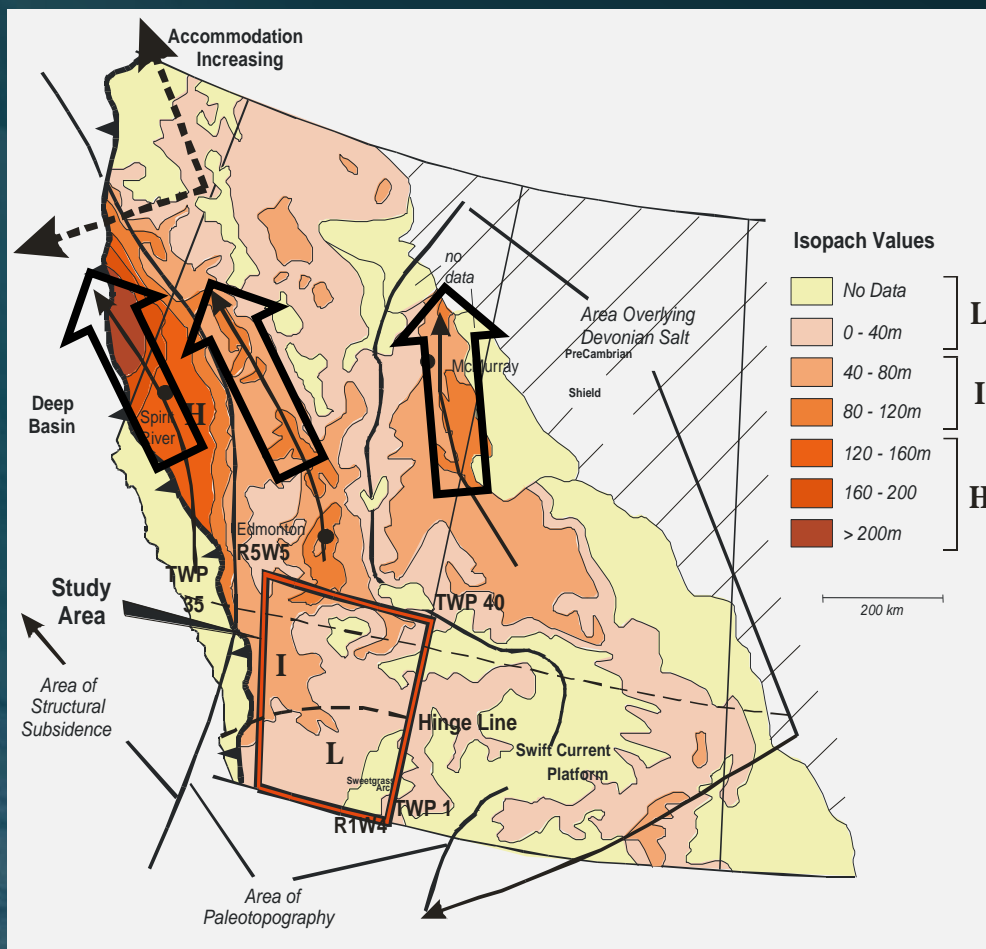


Paleodrainage

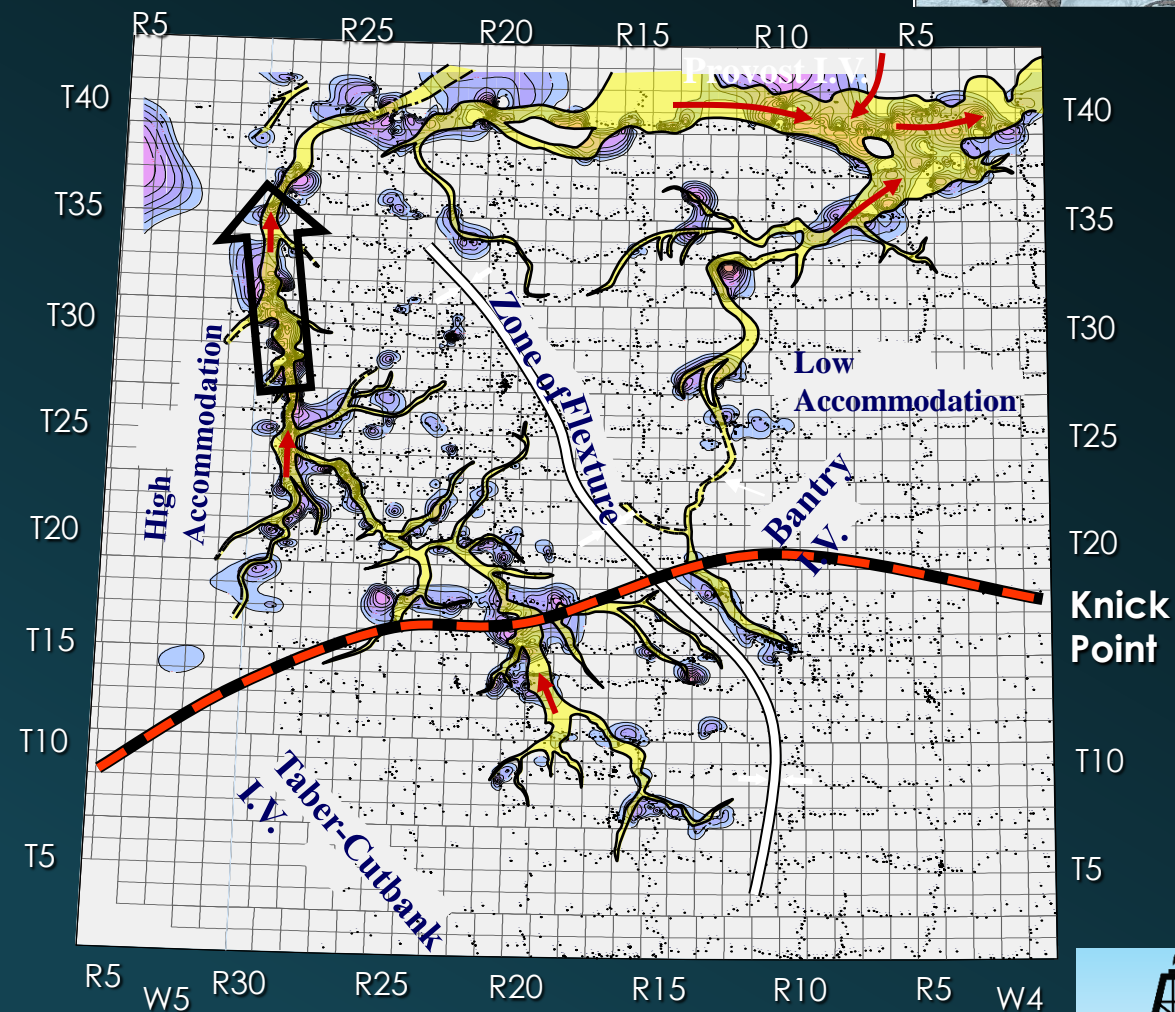
Lower Cretaceous Aptian (120-115 Ma)



Isopach Map
Jurassic to Ostrocod and equivalents



Isopach Map – “BAT” Cycle 2

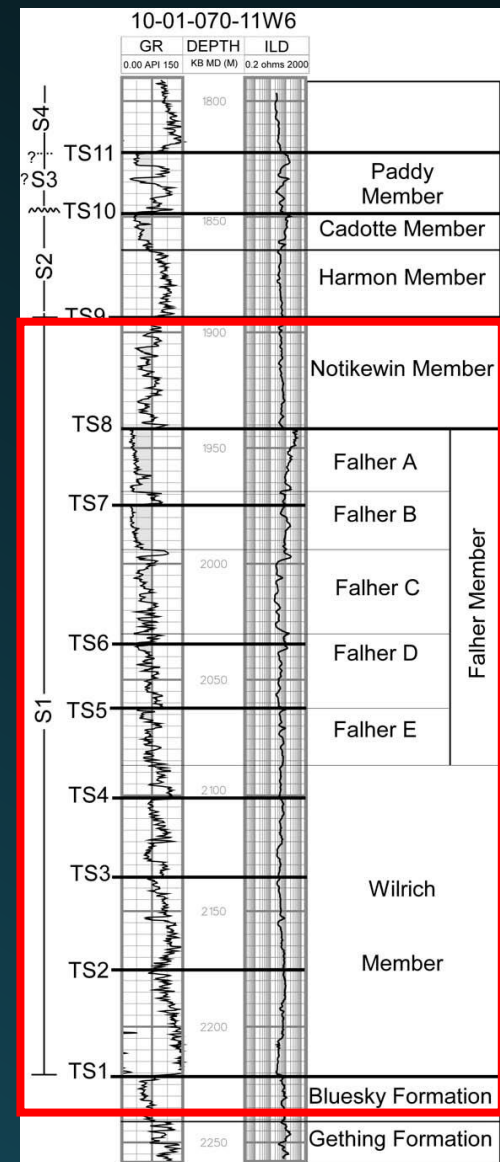
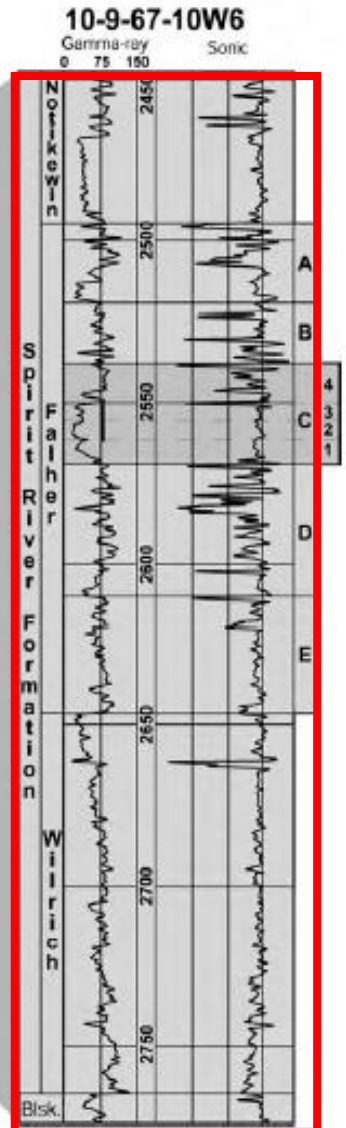
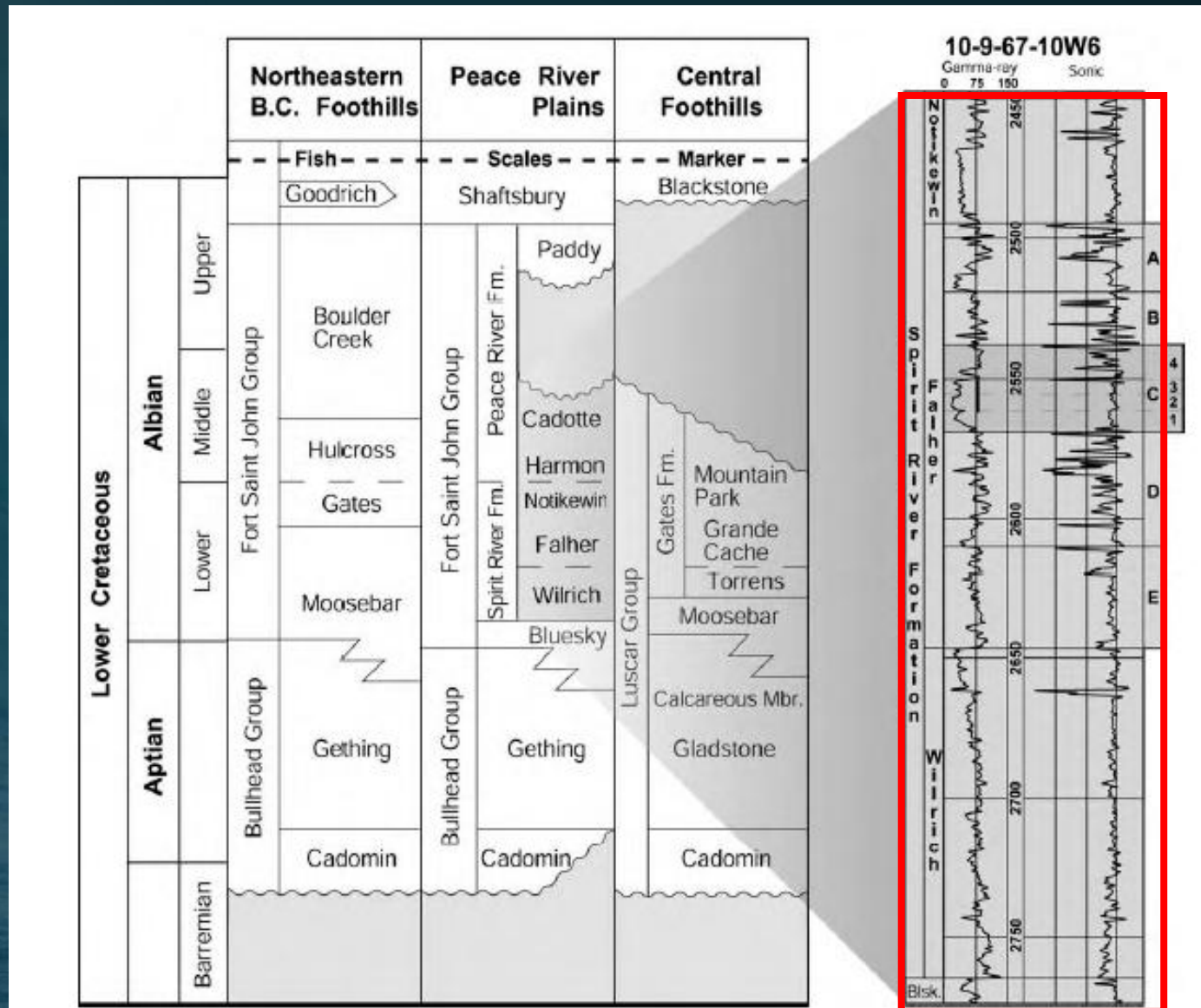


(modified from Cant and Abramson; Zaitlin et al, 2002)

Zaitlin et al, 2002)

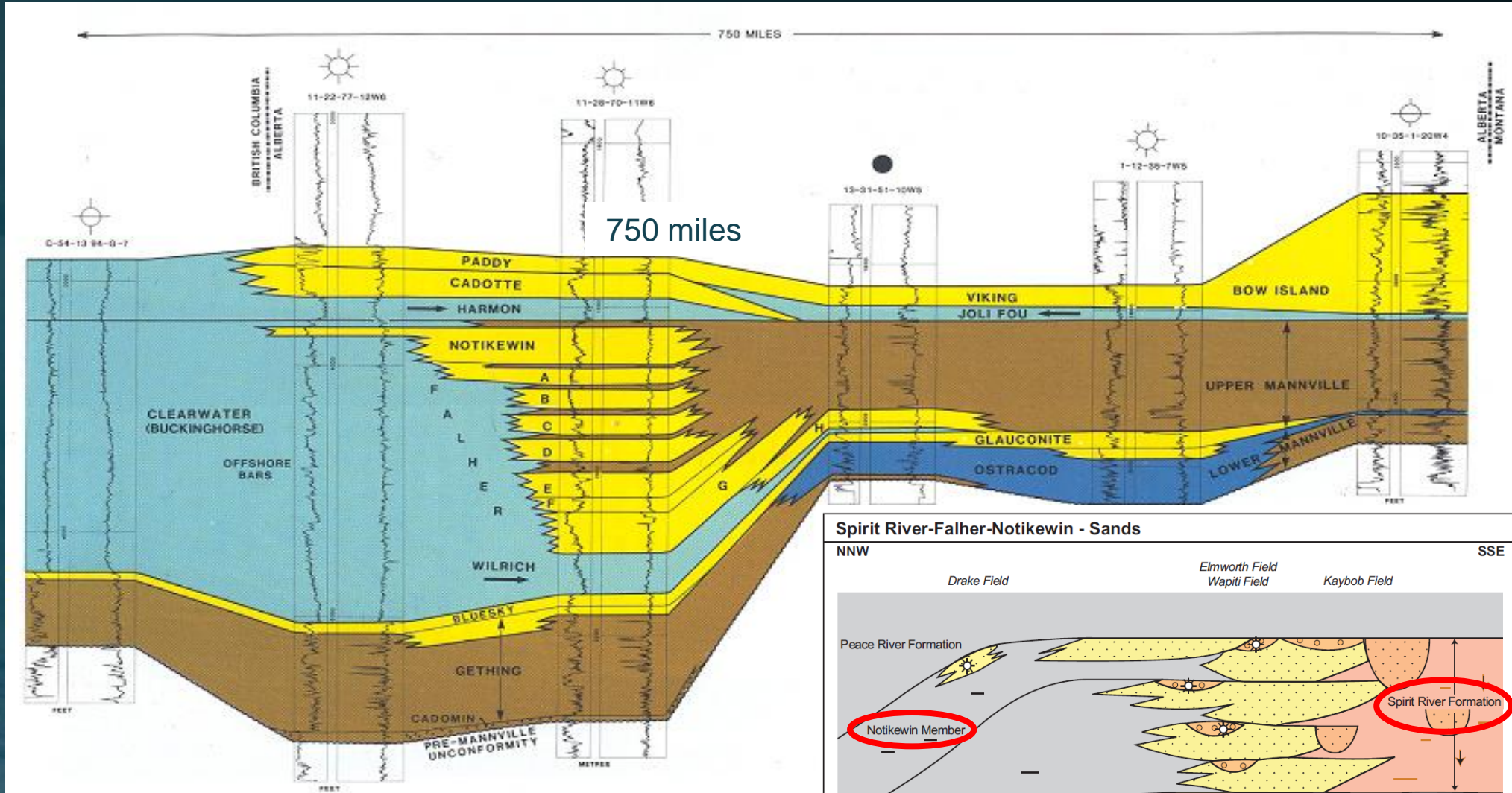


Stratigraphy – Fort St. John – Spirit River Groups

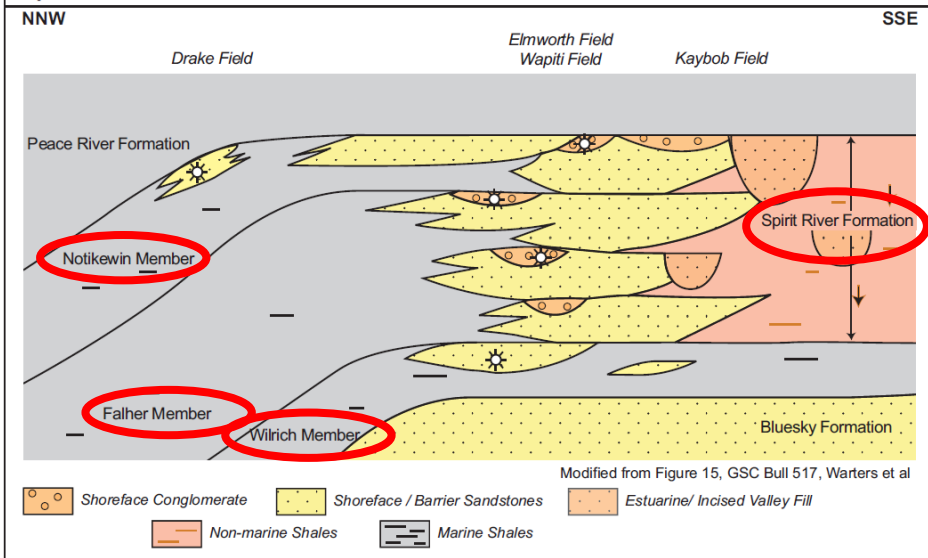


Modified after Masters, 1984

Lower Cretaceous Depositional Cycles



Spirit River-Falher-Notikewin - Sands



(Jackson, 1984)

Parasequence Sets

CDD

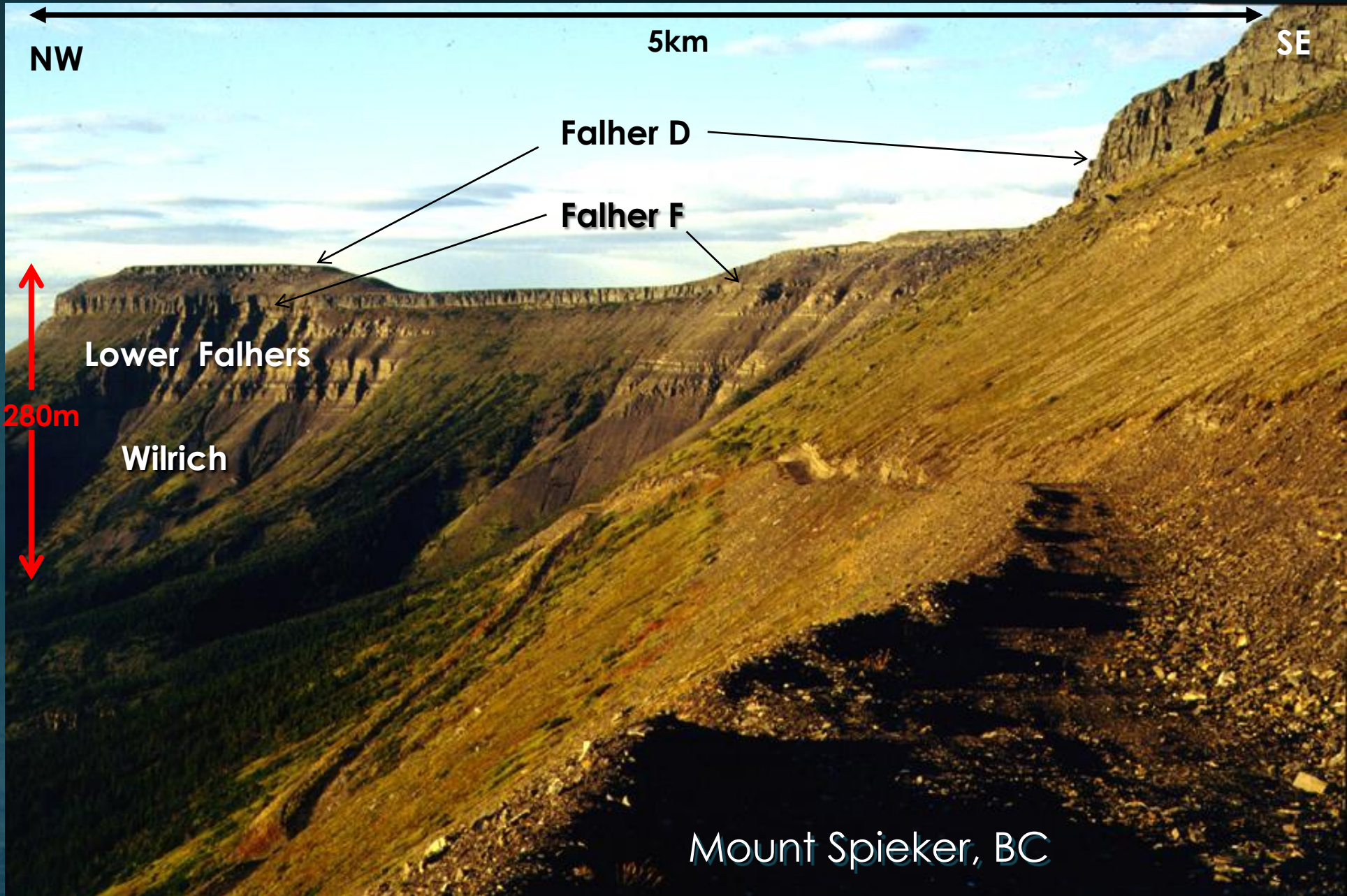
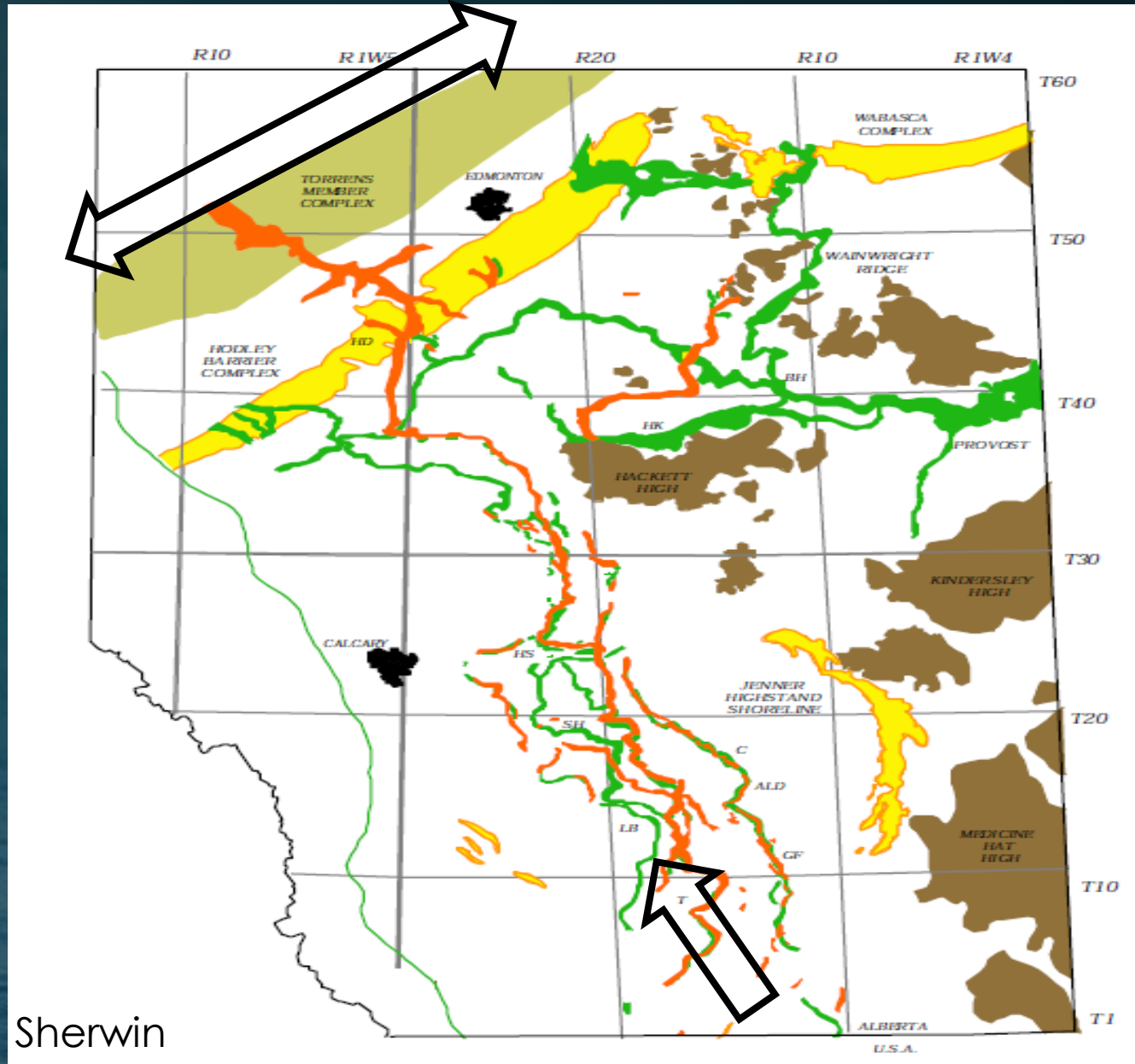


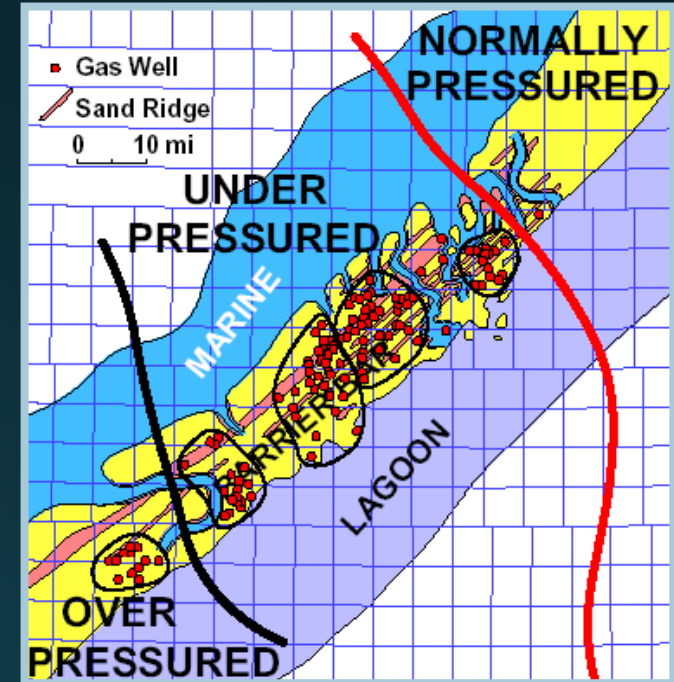
Photo Credit – Tom Moslow

Glauconitic Paleogeography

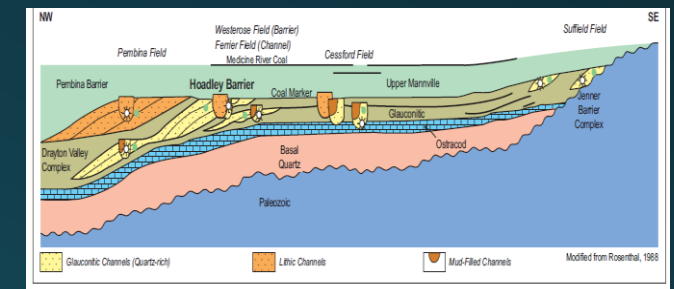


Sherwin

- Shorelines
- GLCC Age Channels
- Post GLCC Incised Valley fill deposits



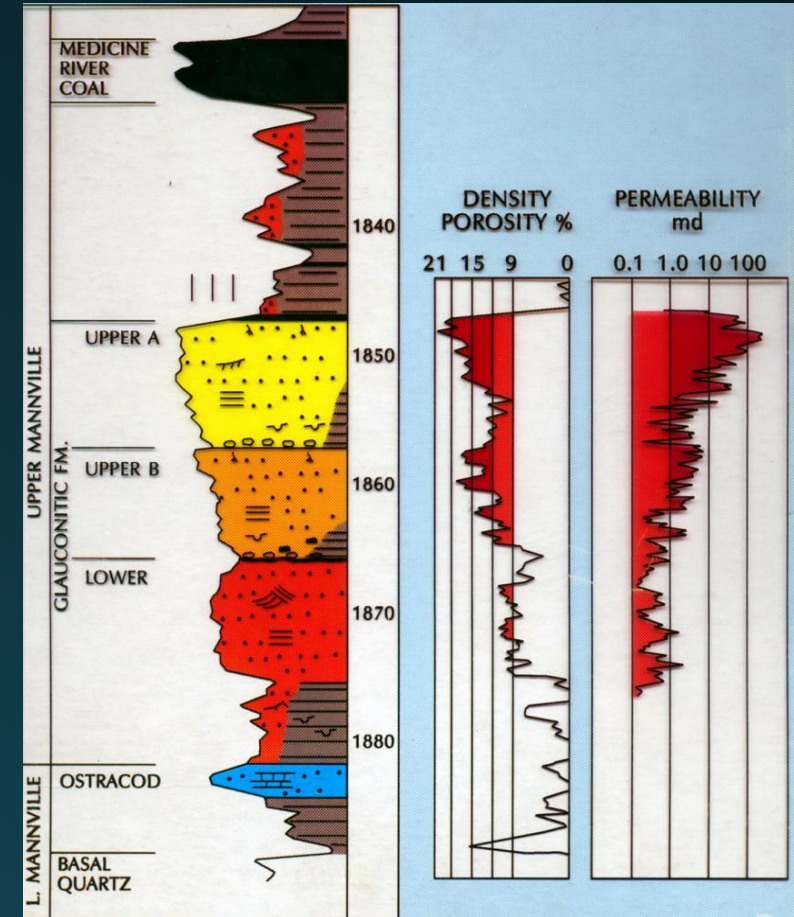
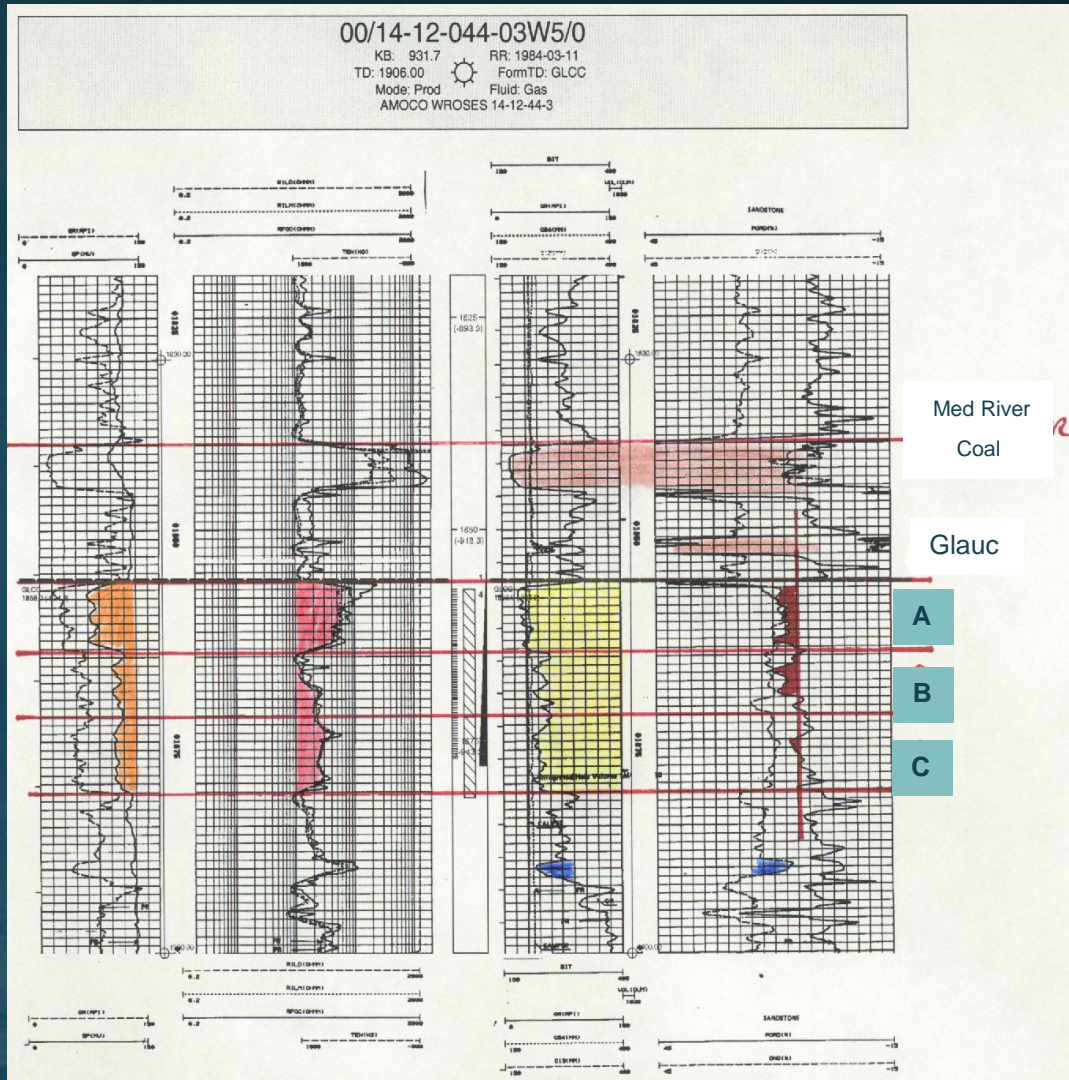
Surdam, 1997,
modified
from Chiang,
1984



CDD

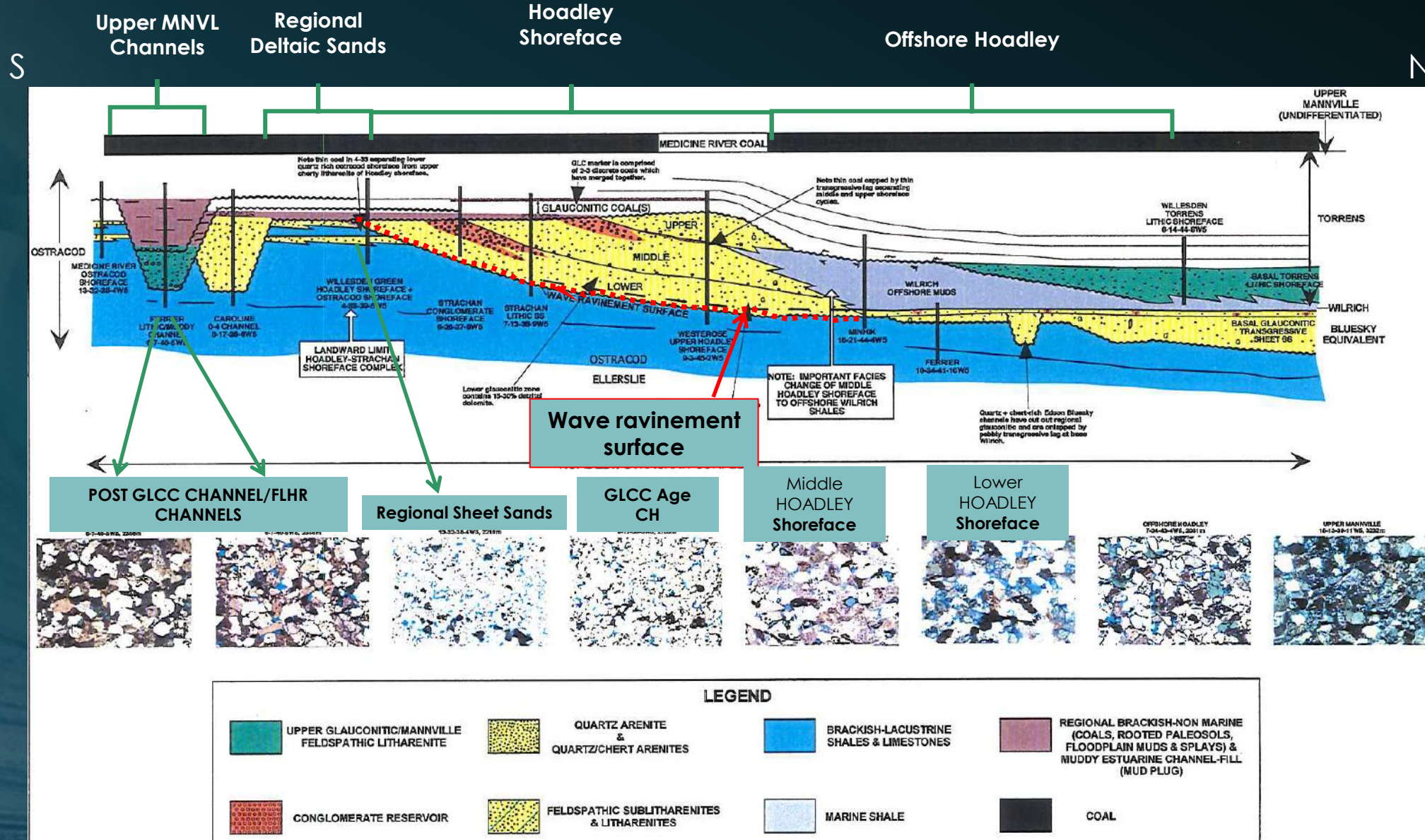


Example Log – Hoadley Barrier



(modified after Rosenthal, 1998)

Glauconitic Hoadley Type Schematic Cross Section SE-NW



Simons, 2015; modified after Rosenthal, 1998

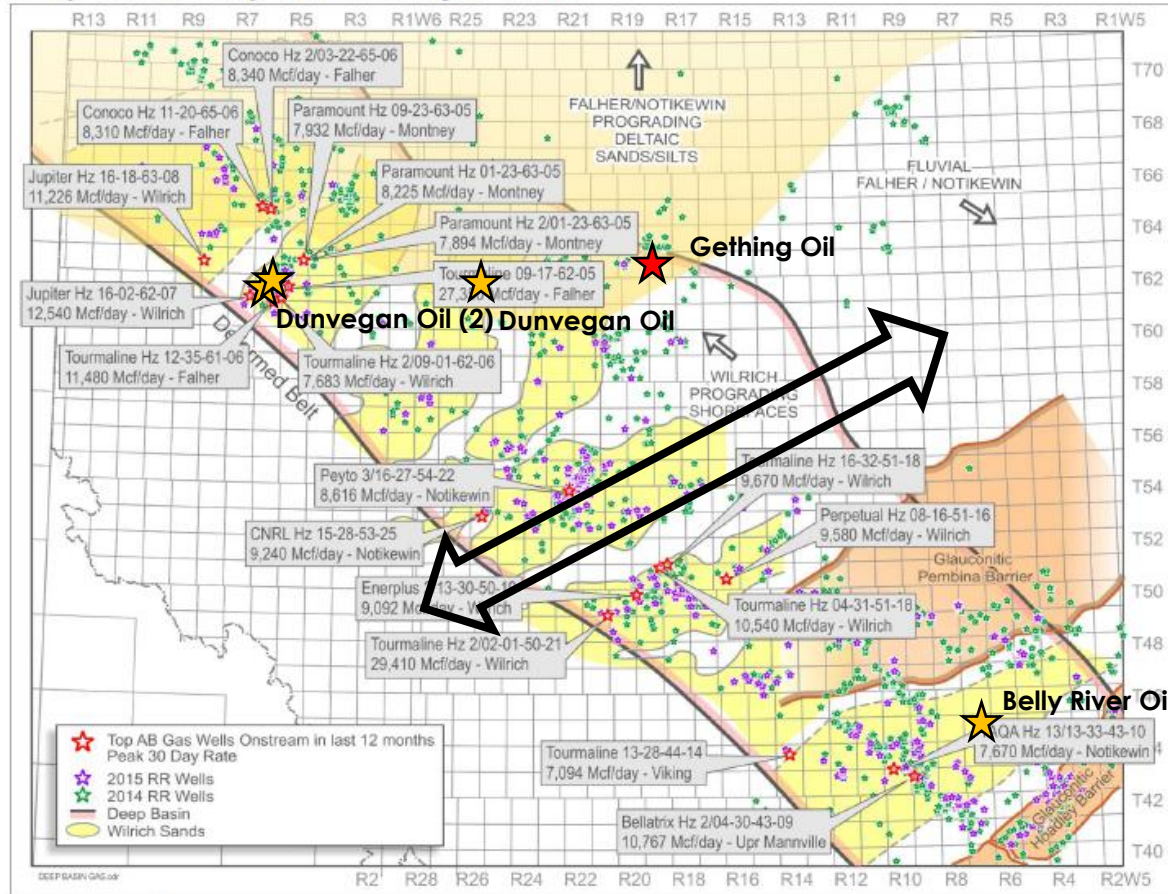
Top 2015 Drilling Activity

Oil

- ★ Overfilled Foreland Basin
- ★ Underfilled Foreland Basin

Spirit River Reservoir Trends in yellow

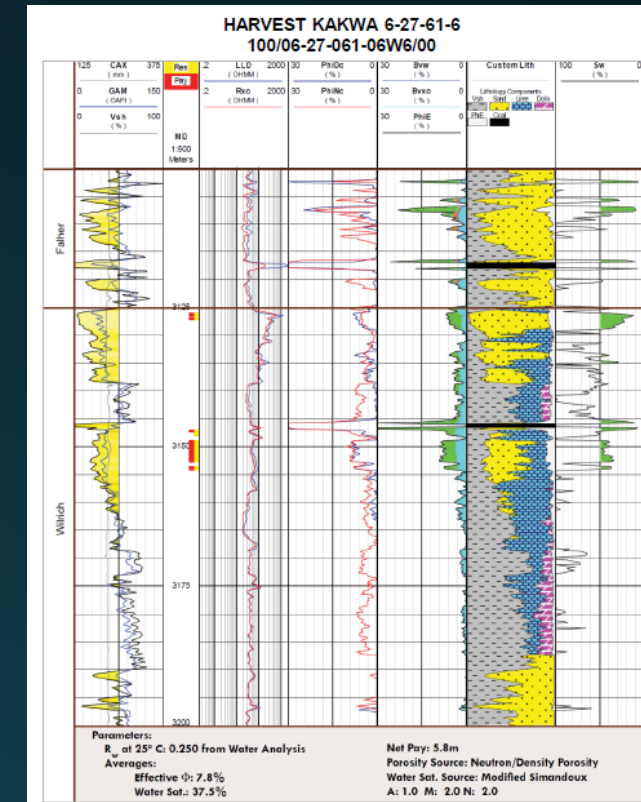
Deep Basin – Top Well Activity in 2015



(1): Scotiabank Geoscout, September 2015



C. Stephens,
CSUR Luncheon
Presentation, 2016



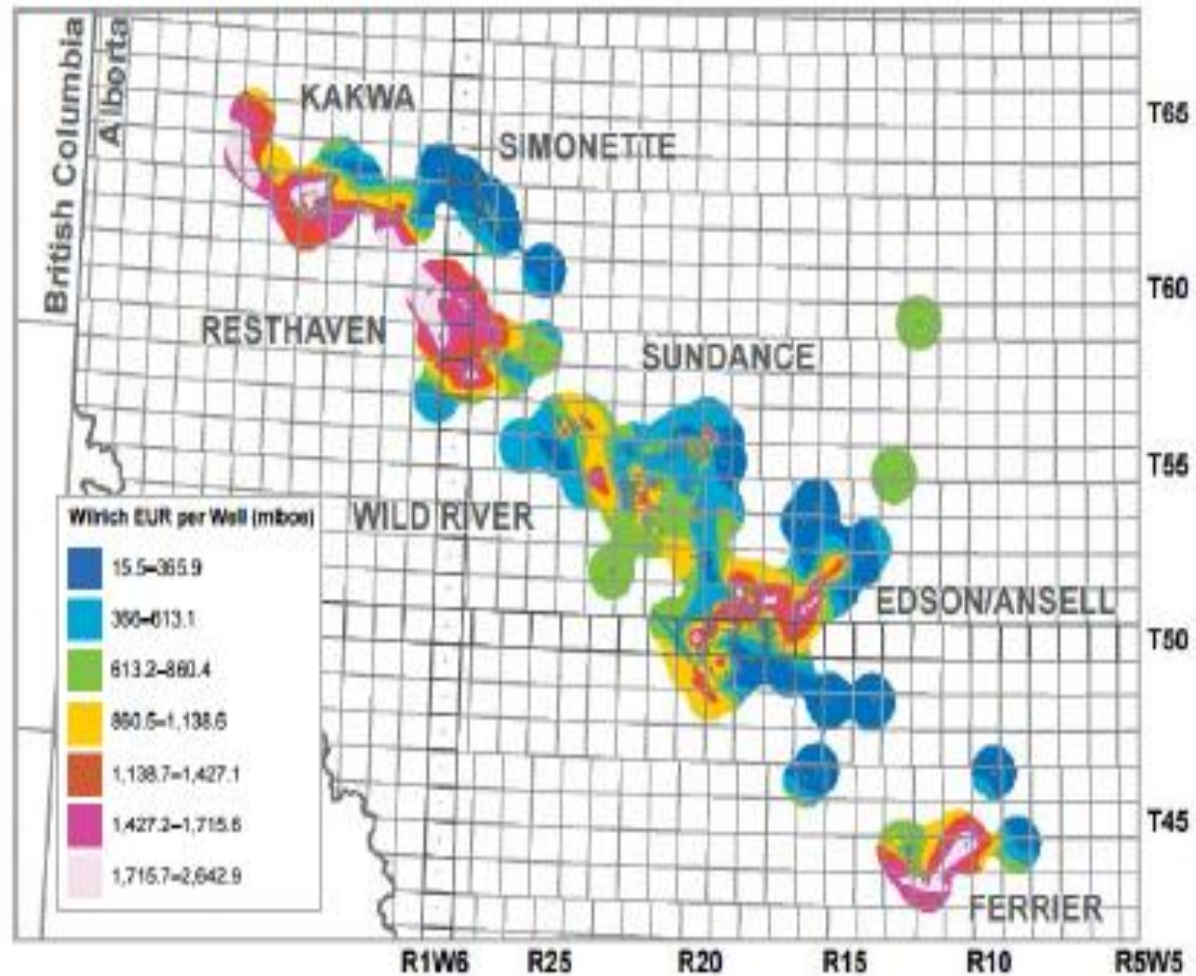
CDD



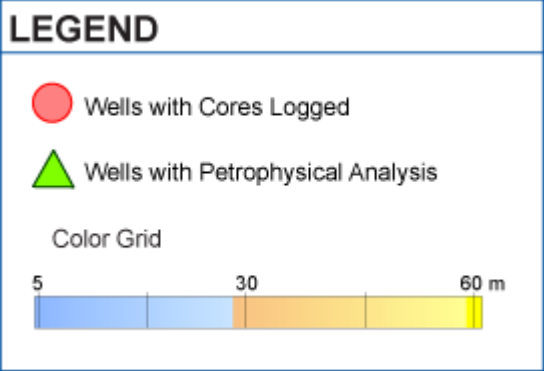
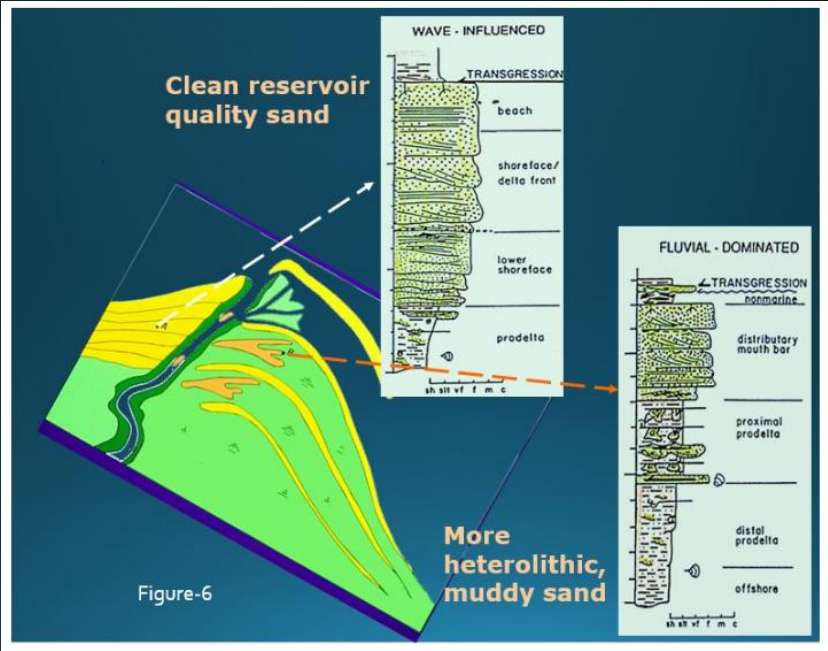
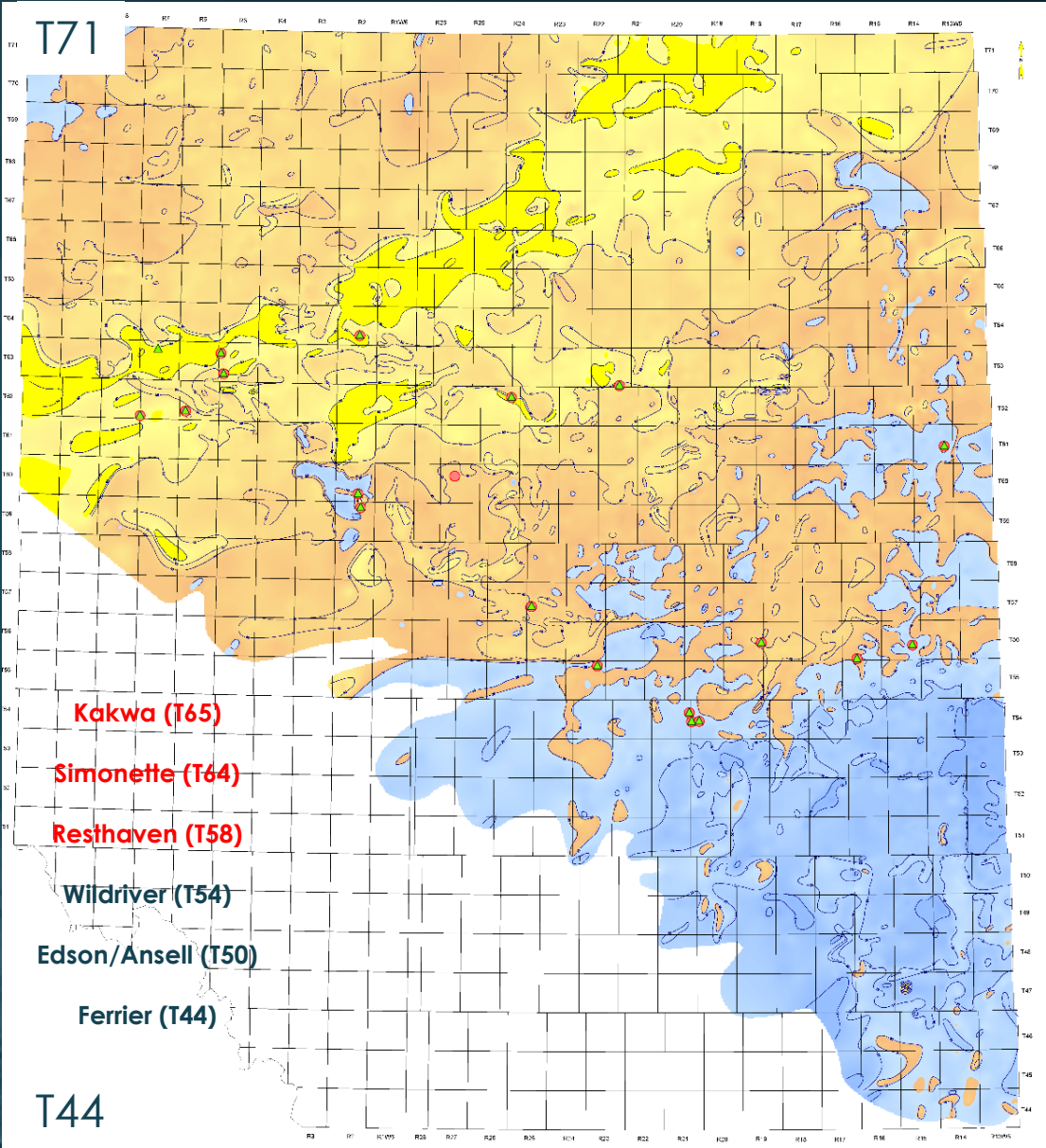
Spirit River – Wilrich EURs

Facies, Depositional model vs. Technology

Wilrich EUR per Well

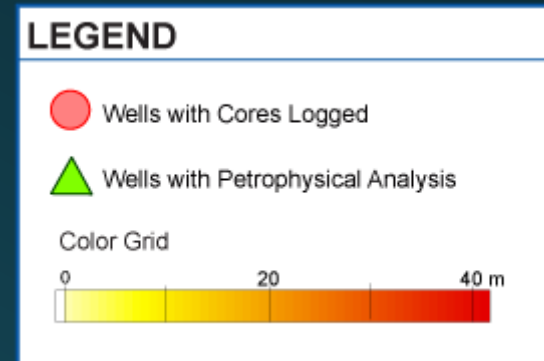
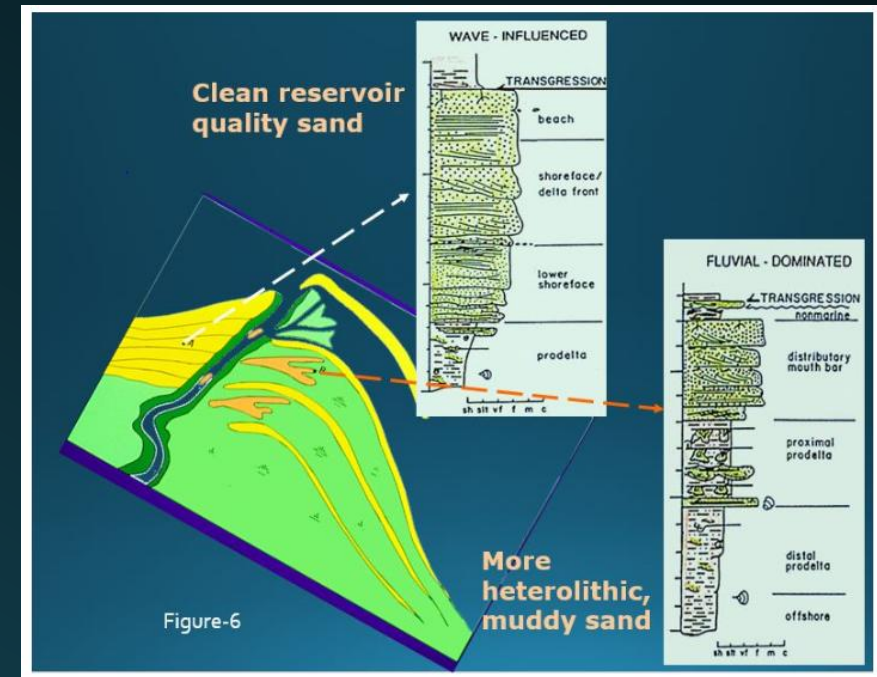
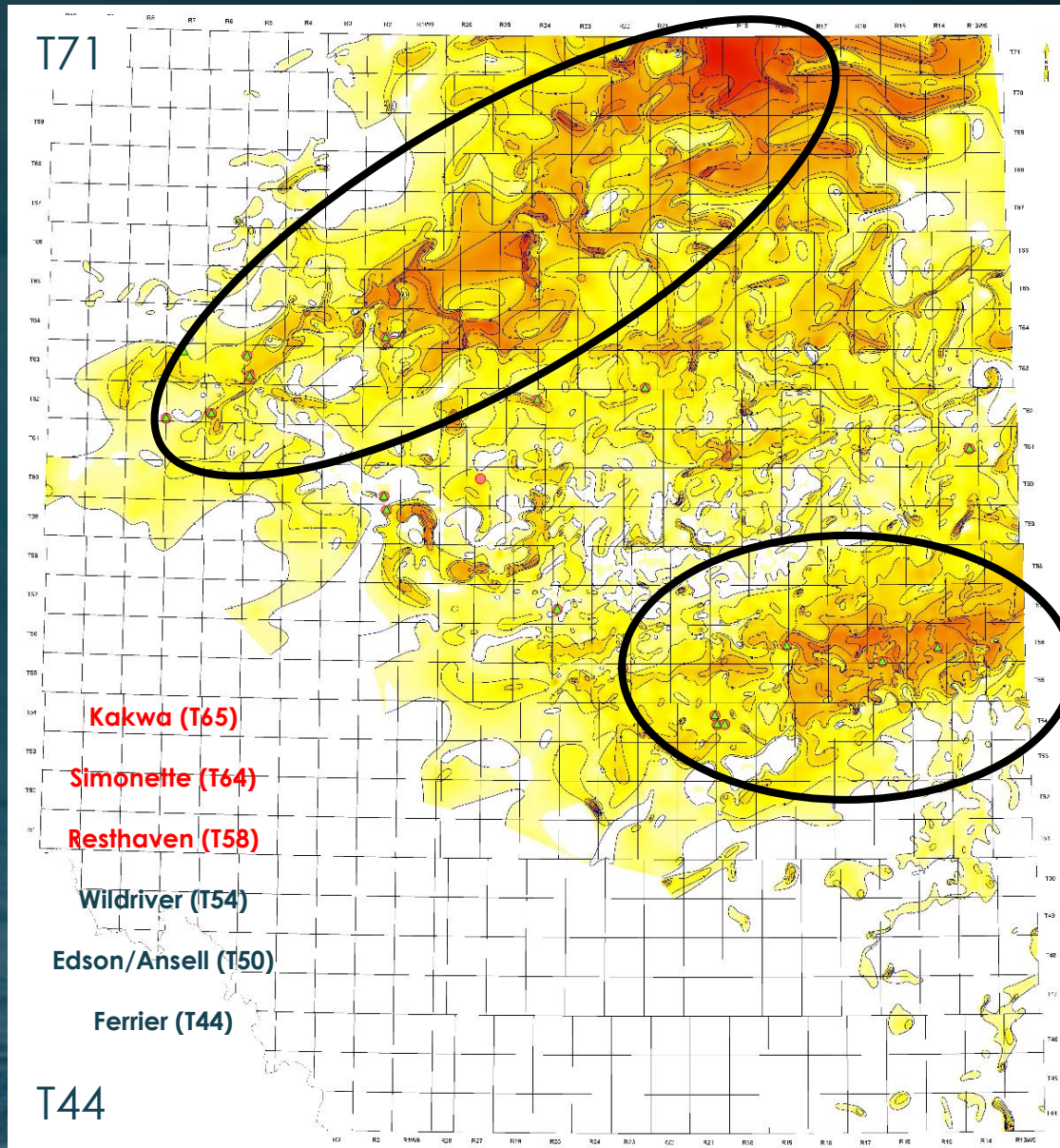


Wilrich A – Gross Isopach

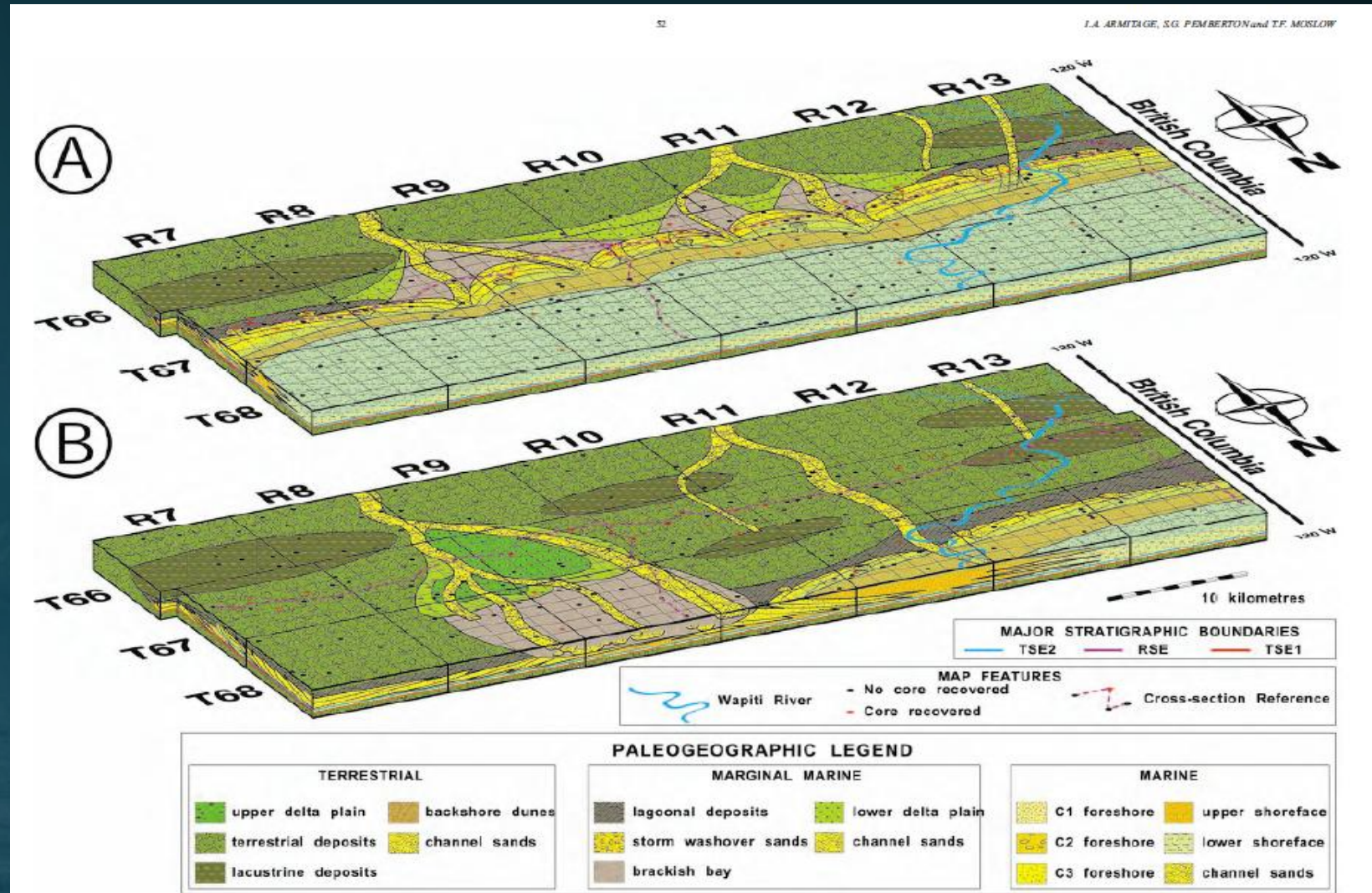


B. Hayes, PRCL, 2013

Wilrich A – Net Porous Sand (6% Ø cutoff)



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)

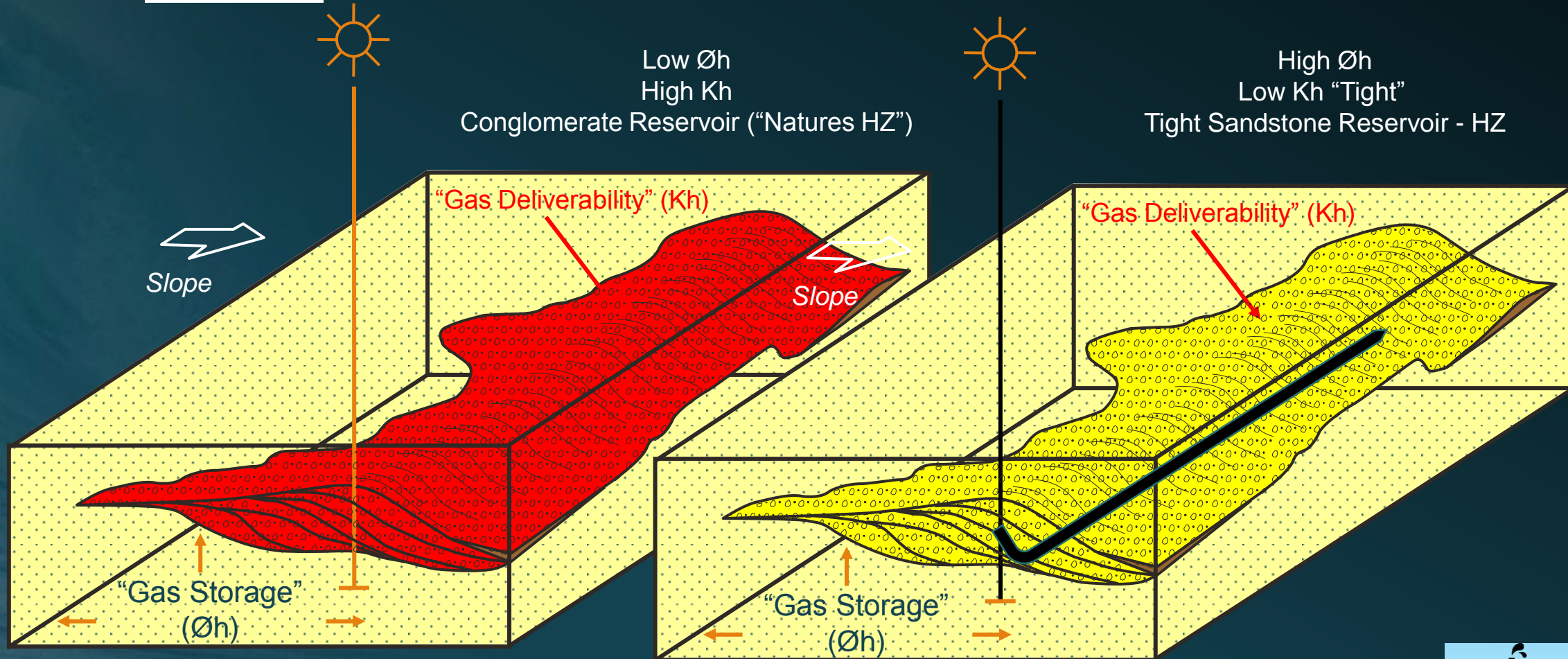
Conglomeratic (Falher)

vs.

Fine Grained Sandstone (Wilrich) Shoreface Reservoirs

HPBCGA "Sweet Spots" act as a HZ well
Dual Transmissivity System

HPBCGA "Sweet Spots" require a HZ well
Dual Transmissivity System



Falher A & B Reservoirs

Wilrich Reservoirs

Modified after Zaitlin and Moslow, 2004

Western Canada Sedimentary Basin

Overfilled Foreland Basin Examples

Era	System	Series	Age	Alberta - Generalized Stratigraphy	Petroleum System Element		
Cenozoic	Quaternary	QUATERNARY	2.6				
		Tertiary	PLIOCENE	55.8			
			PALEOCENE	65.5			
	Mesozoic	Cretaceous	Upper		Paskapoo Fm.	Overburden	
					Edmonton Gp.		
					Belly River Fm. Lea Park Fm.		
			Lower	Colorado Group		Colorado Shale	Seal
						Cardium Fm.	Reservoir
						Second White Speckled Shale	Source/Reservoir
		Colorado Group			Fish Scale zone	Seal	
					Viking Fm. Joli Fou Shale	Reservoir	
					Joli Fou Shale	Seal	
		Jurassic	Upper	Mannville Gp.		Upper Mannville	Reservoir
						coal	Source/Reservoir
						Ostracode zone	Source
Lower	Mannville Gp.			Lower Mannville	Reservoir		
					Unconformity		
Fermie Gp.	Upper	Upper Fernie	Seal				
	Middle						
	Lower	Poker Chip Shale Member	Seal/Source				
		Nordegg, Gordondale Members	Seal/Source				
Paleozoic	Triassic	Upper	Schooner Creek Group				
		Middle	Doig Fm.				
		Lower	Montney Fm.	Source/Seal/Reservoir			
	Permian	Upper	Ishbel Group				
		Lower	Spray Lakes Group				
	Pennsylvanian	Upper					
	Carboniferous	Mississippian	Middle	Rundle Group	Seal/Reservoir		
			Lower	Banff Formation	Source(?)/Seal/Reservoir		
				Exshaw, Bakken Fms.	Source/Reservoir		
	Devonian	Upper		Wabamun Group, Winterburn Group	Seal/Reservoir		
				Woodbend Group	Seal/Reservoir		
				Duvernay Formation	Source		
		Middle		Beaverhill Lake Group	Source/Reservoir		
				Elk Point Group	Source/Reservoir		
Cambrian-Ordovician	Silurian	Lower	Interlake Group - Winnipeg Fm.	Seal/Reservoir			
			Deadwood Fm. - Basal Sandstone	Seal/Reservoir			



- 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

Accommodation Cycles

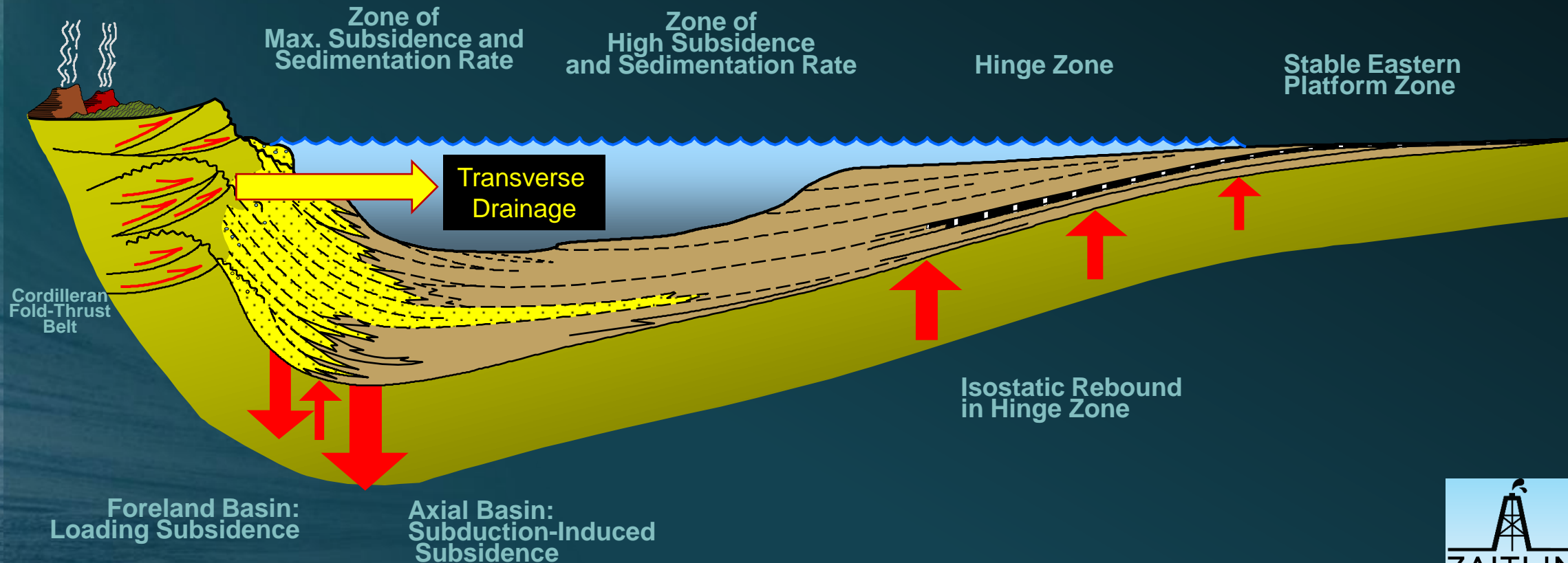
USGS Fact Sheet -
Assessment of
Undiscovered
Conventional Oil and
Gas Resources of the
Western Canada
Sedimentary Basin,
Canada, 2012



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

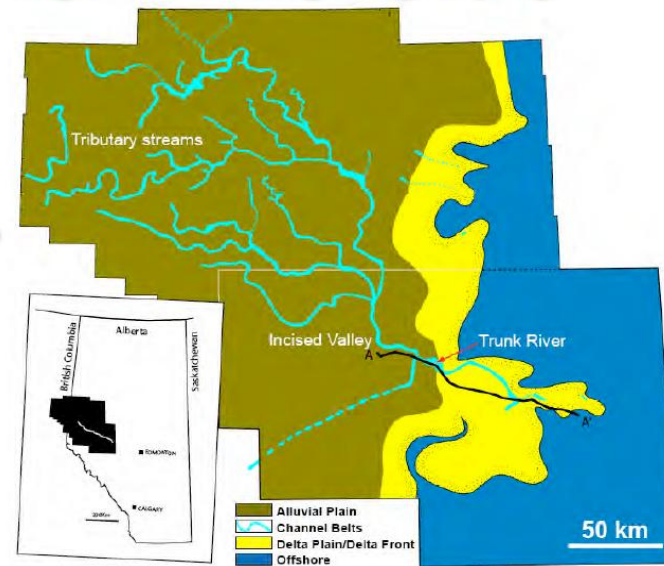
Dunvegan Formation



Bhattacharya and MacEachern, 2010

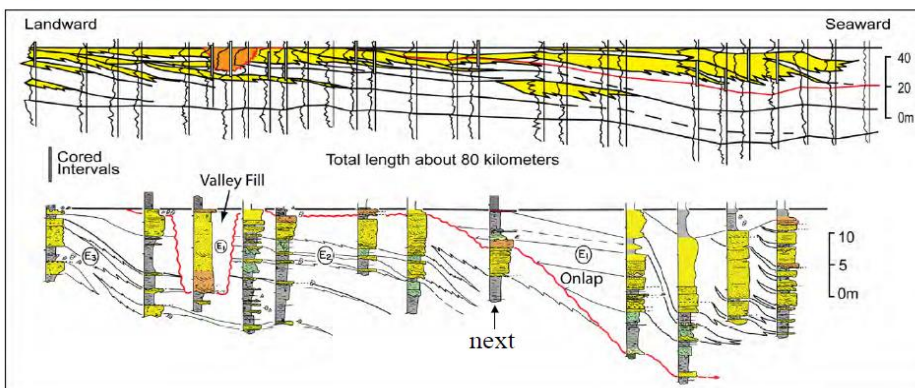
Dunvegan Paleogeography

- 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.



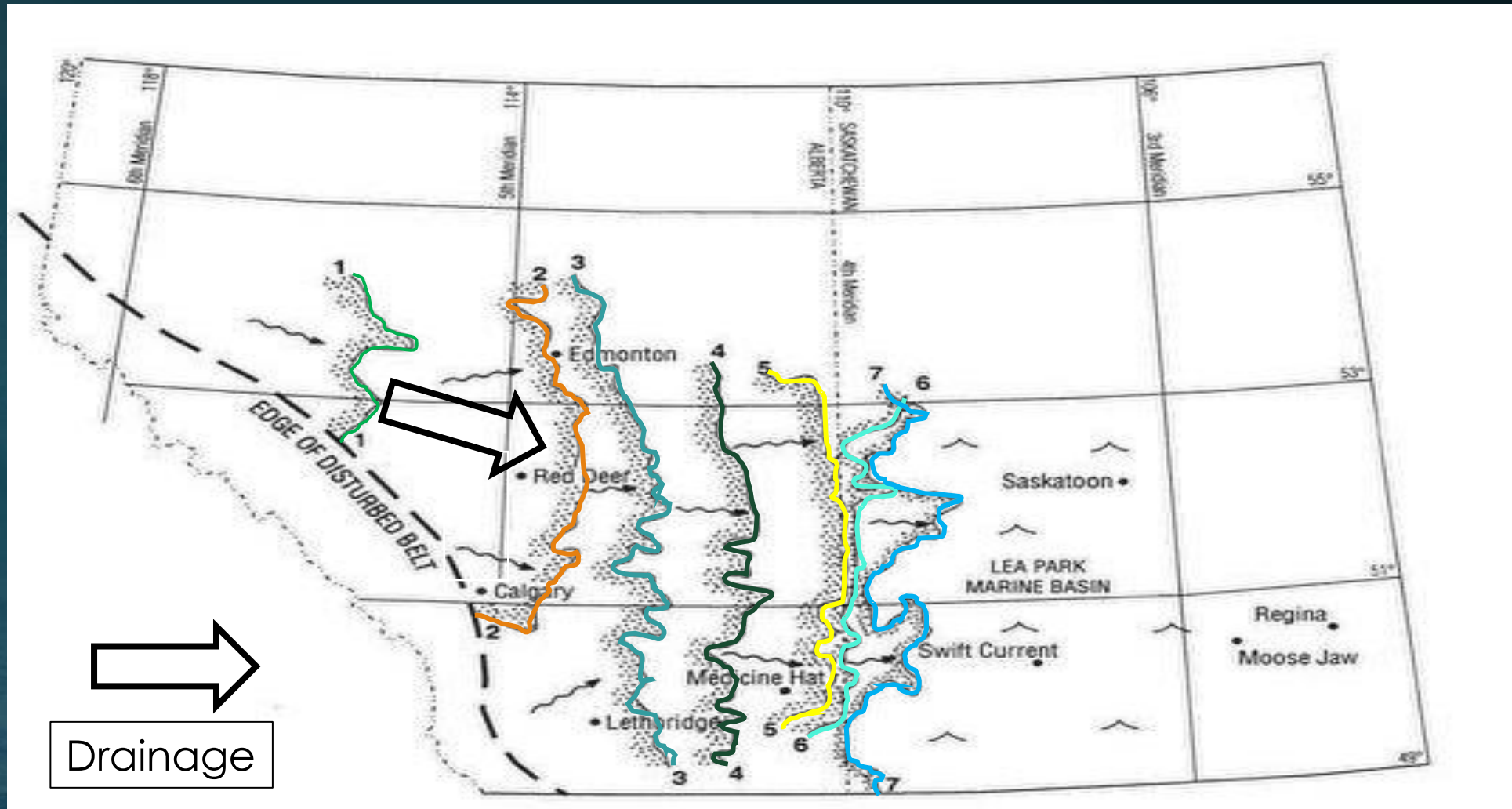
Plint and Wadsworth, 2003

A Dip Cross section Allomember E A'



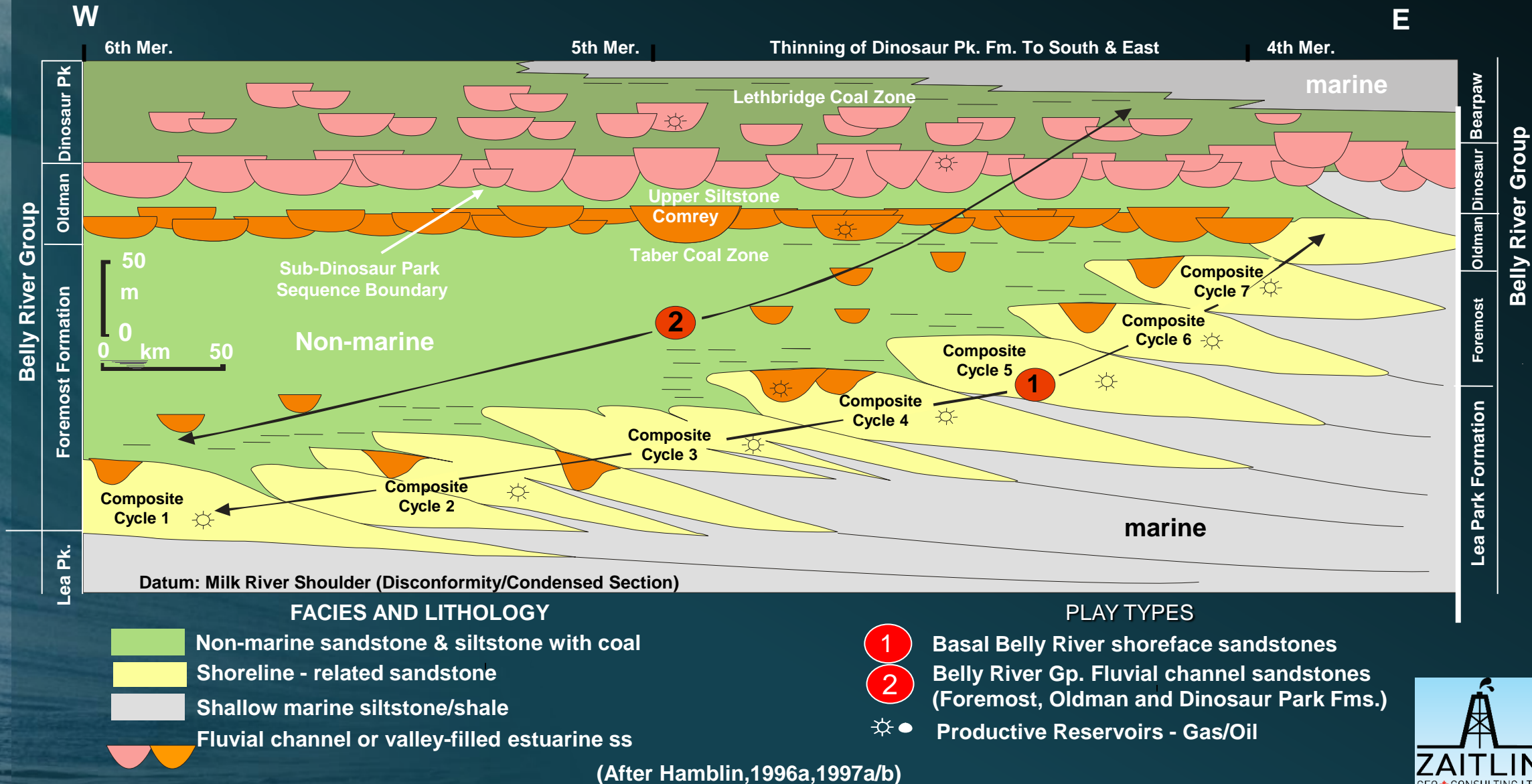
- Feeder valleys can be linked to age-equivalent delta and prodelta facies.

Basal Belly River Prograding Shorelines Overfilled Foreland Basin



(After Hamblin, 1996a, 1997a/b)

Belly River Group Stratigraphy and Play Types



Western Canada Sedimentary Basin (WCSB)

Foreland Basin

Pre- Foreland Basin

Era	System	Series	Age Ma.	Alberta - Generalized Stratigraphy	Petroleum System Element			
Cenozoic	Tertiary	Pliocene	2.6					
			55.8					
Cretaceous	Upper	Colorado Group	65.5	Paskapoo Fm.	Overburden			
				Edmonton Gp.				
				Belly River Fm.				
				Lea Park Fm.				
				Colorado Shale	Seal			
				Cardium Fm.	Reservoir			
				Second White Speckled Shale	Source/Reservoir			
				Fish Scale zone	Seal			
				Viking Fm.	Reservoir			
				Joli Fou Shale	Seal			
Mesozoic	Lower	Mannville Gp.	119	Upper Mannville	Reservoir			
				coal	Source/Reservoir			
				Ostracode zone	Source			
				Lower Mannville	Reservoir			
			150	Unconformity				
			Jurassic	Upper	Fernie Gp.	161	Upper Fernie	Seal
						176	Poker Chip Shale Member	Seal/Source
							Nordegg, Gordondale Members	Seal/Source
			Triassic	Upper		228	Schooler Creek Group	
245	Doig Fm.							
	Montney Fm.	Source/Seal/Reservoir						
251								
Paleozoic	Carboniferous	Mississippian	271	Ishbel Group				
			299	Spray Lakes Group				
			318					
			328					
				Rundle Group	Seal/Reservoir			
	Devonian	Upper		345	Banff Formation	Source(?)Seal/Reservoir		
				359	Exshaw, Bakken Fms.	Source/Reservoir		
					Wabamun Group, Winterburn Group	Seal/Reservoir		
					Woodbend Group	Seal/Reservoir		
					Duvernay Formation	Source		
Silurian	Lower		385	Beaverhill Lake Group	Source/Reservoir			
				Elk Point Group	Source/Reservoir			
			397					
			416	Interlake Group - Winnipeg Fm.	Seal/Reservoir			
			444	Deadwood Fm. - Basal Sandstone	Seal/Reservoir			

Foreland Basin

Overfilled Foreland Basin

Underfilled Foreland Basin

- Edmonton Group
- Belly River
- Cardium
- Dunvegan
- Second White Specks
- Viking
- Joli Fou/Basal Colorado
- Mannville
- Spirit River
- (Wilrich/Father/Notikewan)
- Glauconitic
- Ostrocod
- BQ-Ellerslie
- Fernie, Poker Chip Rock Creek
- Nordegg

Accommodation Cycles



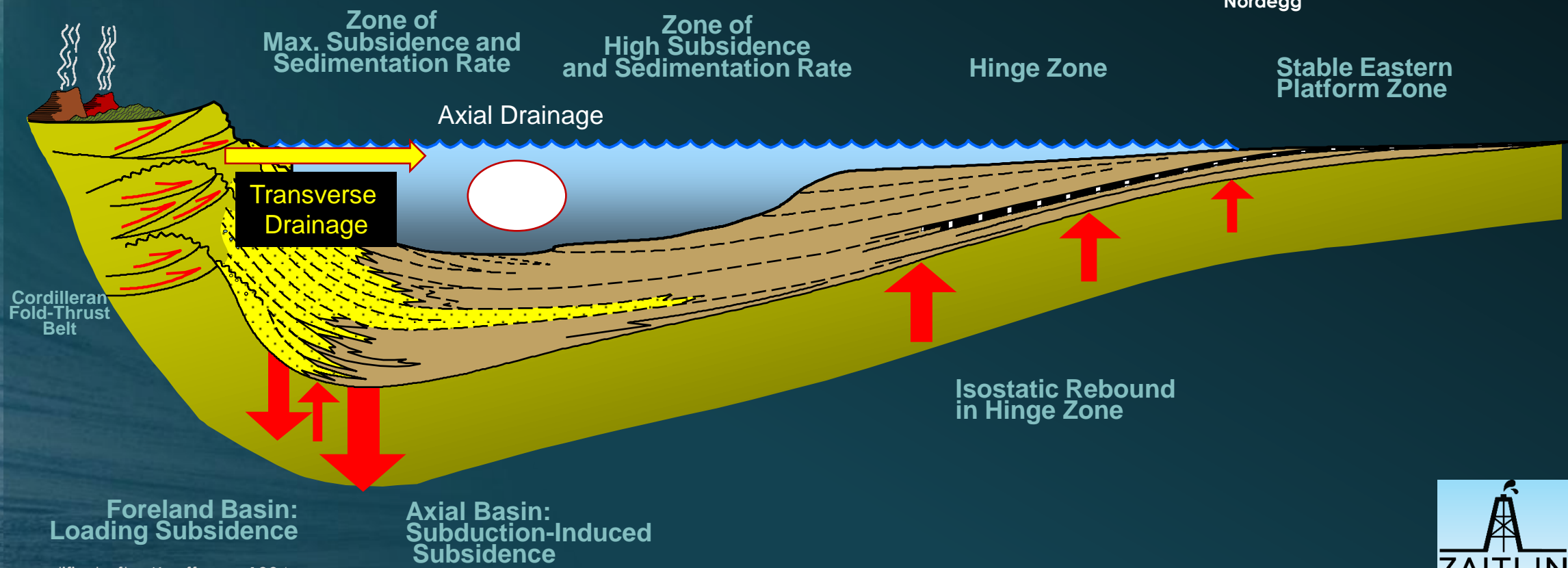
Pre - Foreland Basin

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



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)
 - Glaucconitic
 - Ostrocod
 - BQ-Ellerslie
 - Fernie, Poker Chip Rock Creek
 - Nordegg



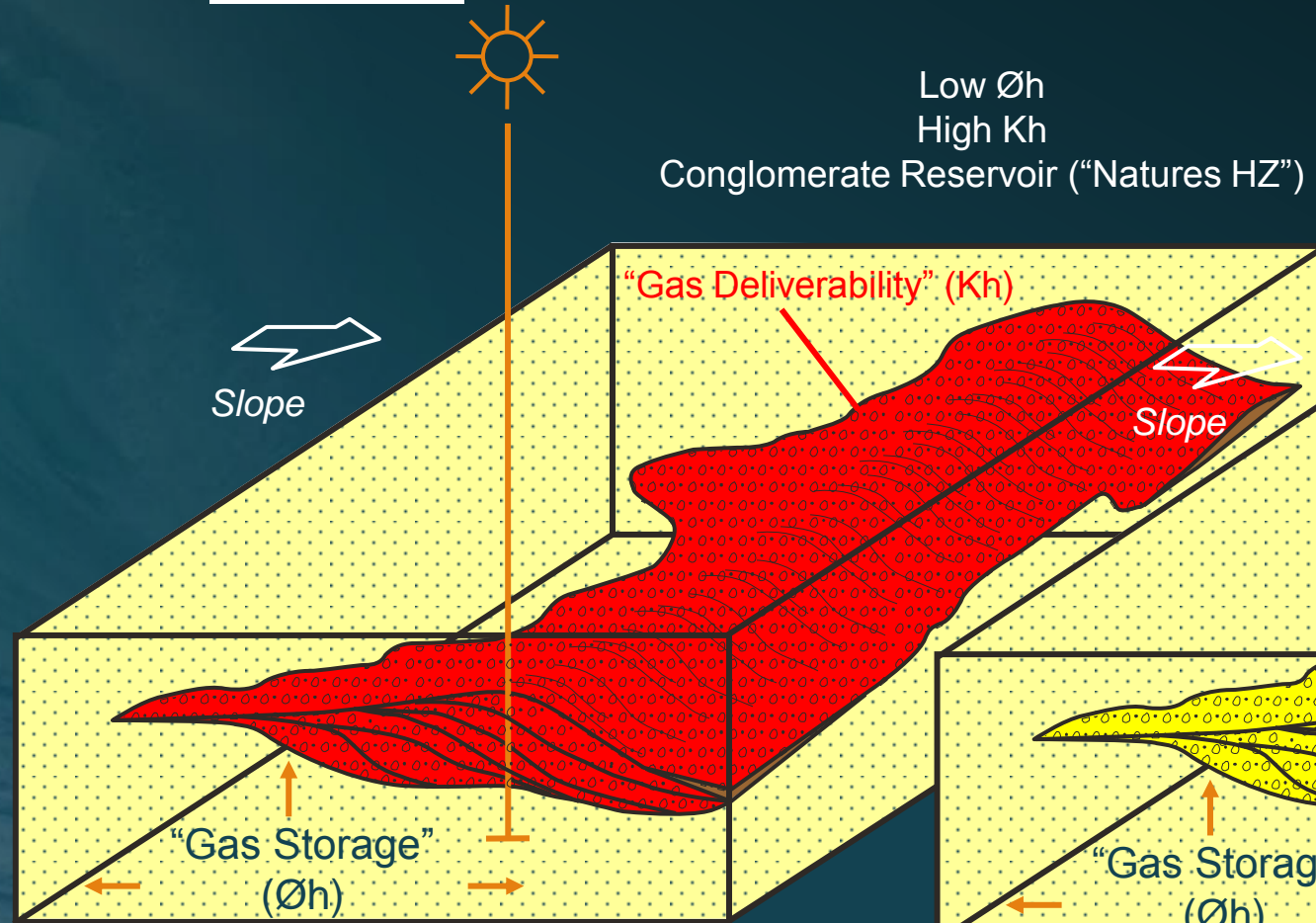
modified after Kauffman, 1984



Conglomeratic (Falher)

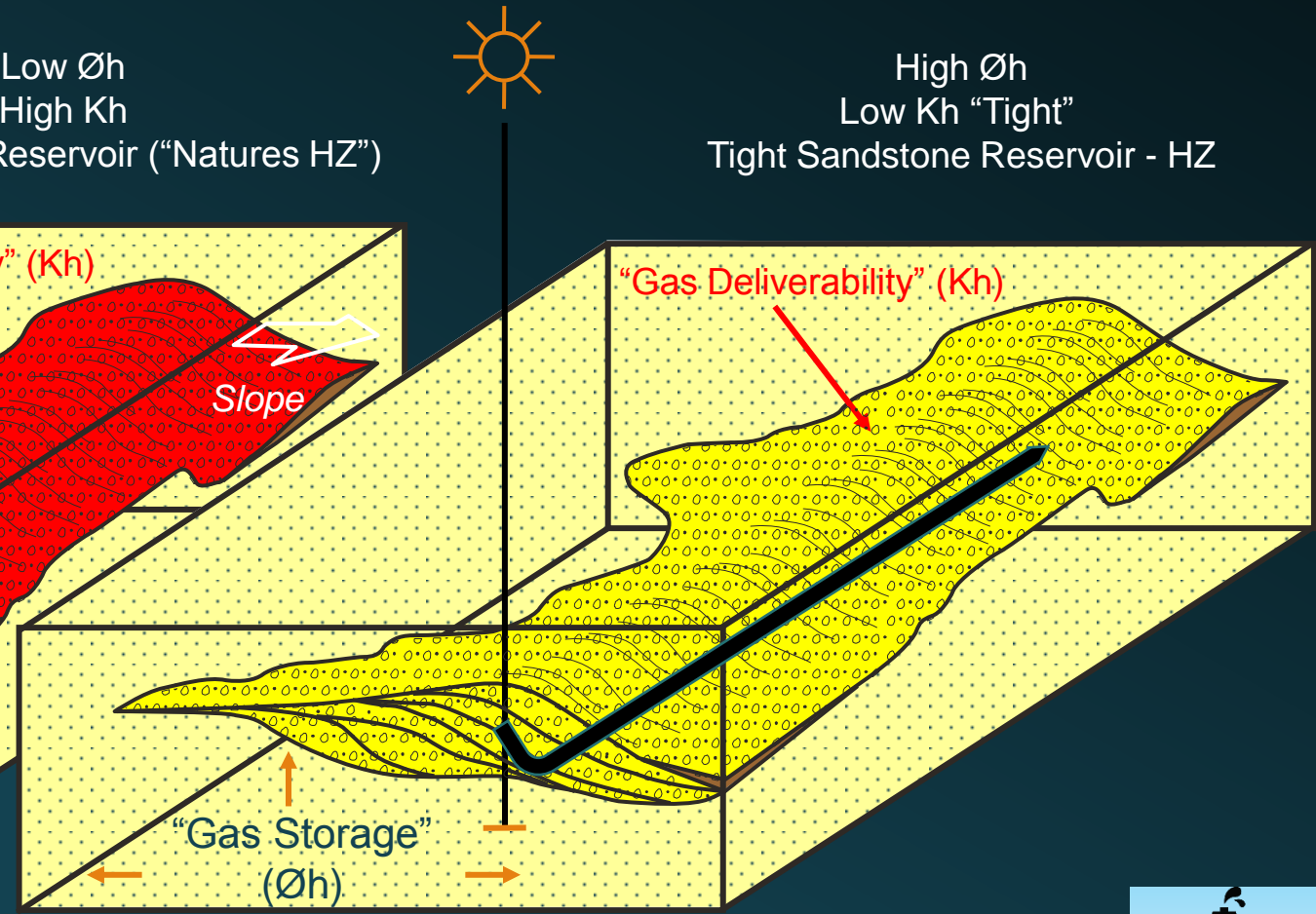
vs.

Fine Grained Sandstone (Wilrich) Shoreface Reservoirs



Falher A & B Reservoirs

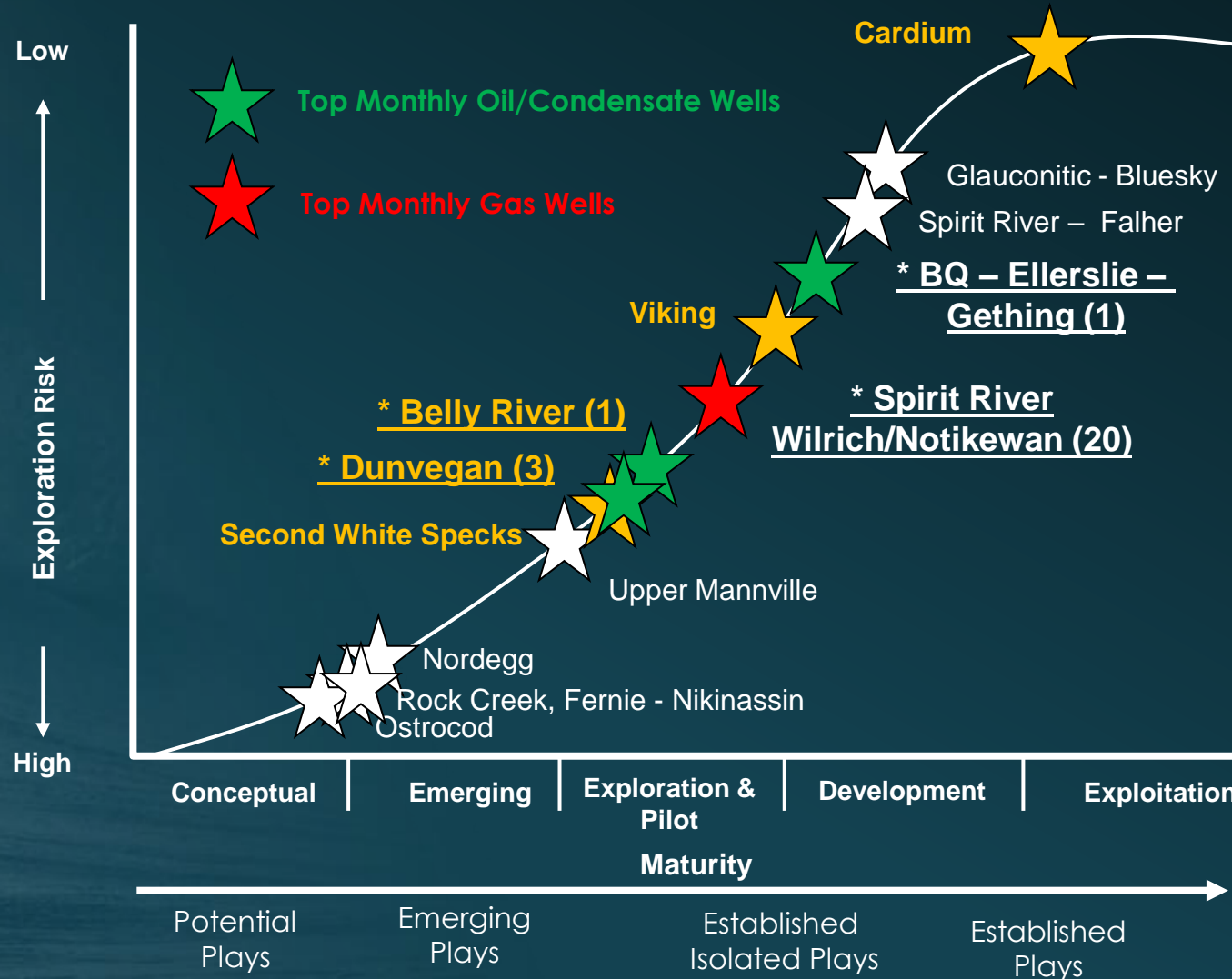
HPBCGA "Sweet Spots" act as a HZ well
Dual Transmissivity System



Wilrich Reservoirs

Modified after Zaitlin and Moslow, 2004

Jurassic-Cretaceous Foreland Basin Unconventional Plays Underfilled vs. **Overfilled** Foreland Basin



Overfilled FB

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

Underfilled FB

Upper Mannville
***Spirit River - Wilrich**
 Glauconitic - Bluesky
 Ostrocod
***BQ-Ellerslie**
 Fernie - Nikinassin
 Rock Creek
 Nordegg

Summary

- **WCSB Foreland Basin is divisible into :**
 - **Underfilled Foreland Basin sequence**
 - **Overfilled Foreland Basin sequence**
 - **Pre-Foreland Basin sequence**
- **Paleodrainage:**
 - **South to north for the underfilled foreland basin**
 - **West to east for the overfilled foreland basin**
- **Shoreline geometry**
 - **East-west for the underfilled foreland basin - Prograding to the north**
 - **North – south for the overfilled foreland basin - Prograding to the east**
 - **Asymmetric Wave-dominated Delta model = “sweetspots”**

Acknowledgements

- **Dr. Brad Hayes**
 - (Petrel Robertson Consulting Ltd.)
- **Dr. Zeev Berger**
 - (Ittech, Inc.)
- **Many Past Colleagues from:**
 - Esso/Exxon
 - PanCanadian/Encana
 - Suncor
 - Enerplus
 - EOG
 - Daylight/Midnight/Pace



One last thought:
"Once you understand that water flows downhill,
then everything makes sense"