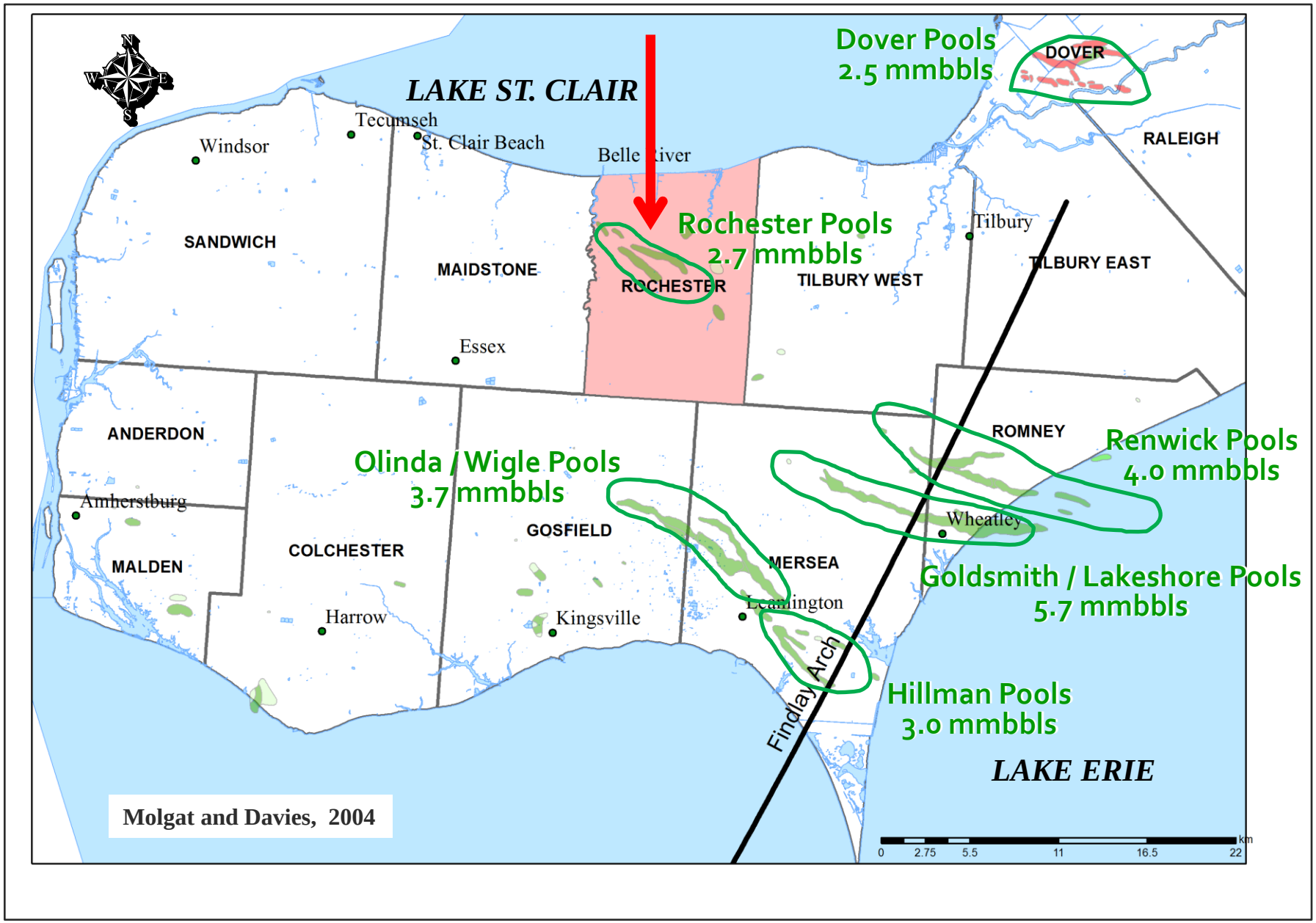
TRENTON- BLACK RIVER HTD RESERVOIRS OF THE MICHIGAN BASIN

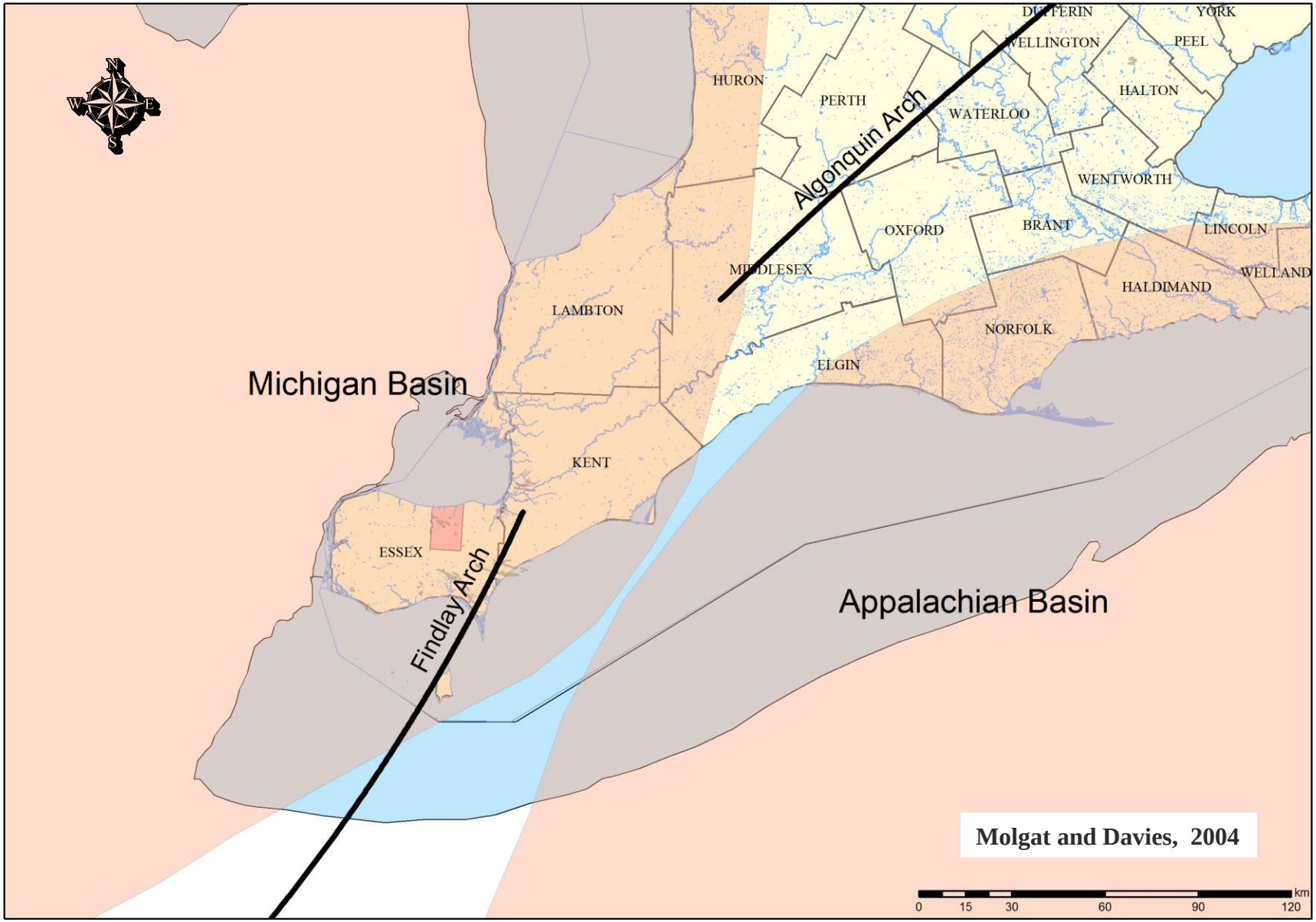
Ian Colquhoun – Ontario

Bill Vansickel - Michigan

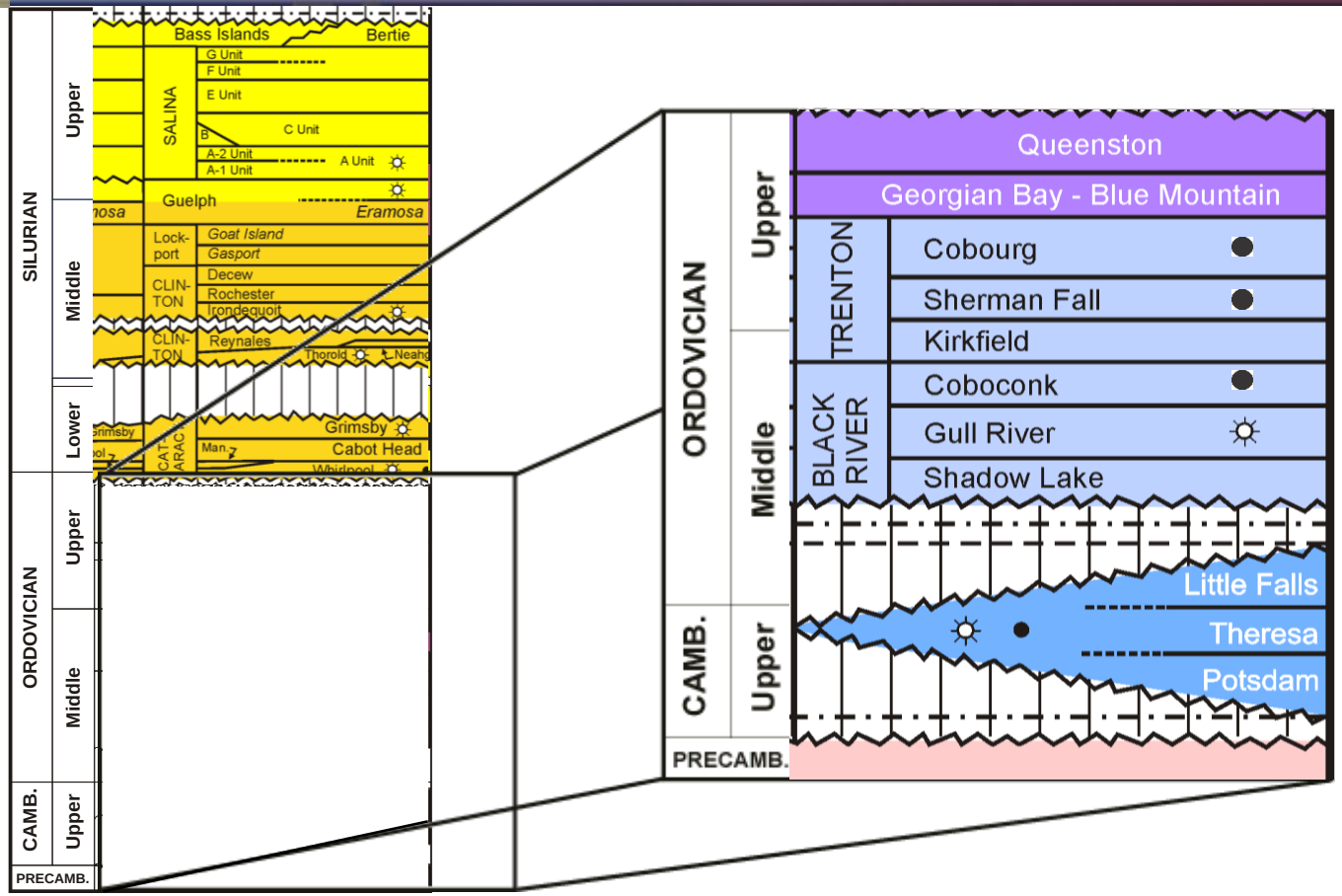

Michigan Basin
Rochester
Algonquin Arch
Albion-Scipio
Northville
Napoleon
Deerfield
Stoney Point
Lima-Indiana
Findlay Arch
Ontario
Lake Erie
New York
Pennsylvania
Saybrook
Limit of Allegheny Deformation
Ohio
Appalachian Basin
Allegheny Front
Cottontree
West Virginia
Appalachian Orogen
BRUCE
HURON
DUFFERIN
WELLINGTON
YORK
DURHAM
PEEL
PRINCE EDWARD
PERTH
WATERLOO
HALTON
WENTWORTH
OXFORD
BRANT
LINCOLN
MIDDLESEX
HALDIMAND
WELLAND
LAMBTON
NORFOLK
ELGIN
KENT
ESSEX
Dover
GLODES CORNERS ROAD
MUCK FARM
SUGAR HILL
TERRY HILL S
WILSON HOLLOW
QUACKENBUSH HILL
Molgat and Davies, 2004
PLAY BY PLAY
EXPLORING THE MICHIGAN BASIN
0 20 40 80 120 160 km

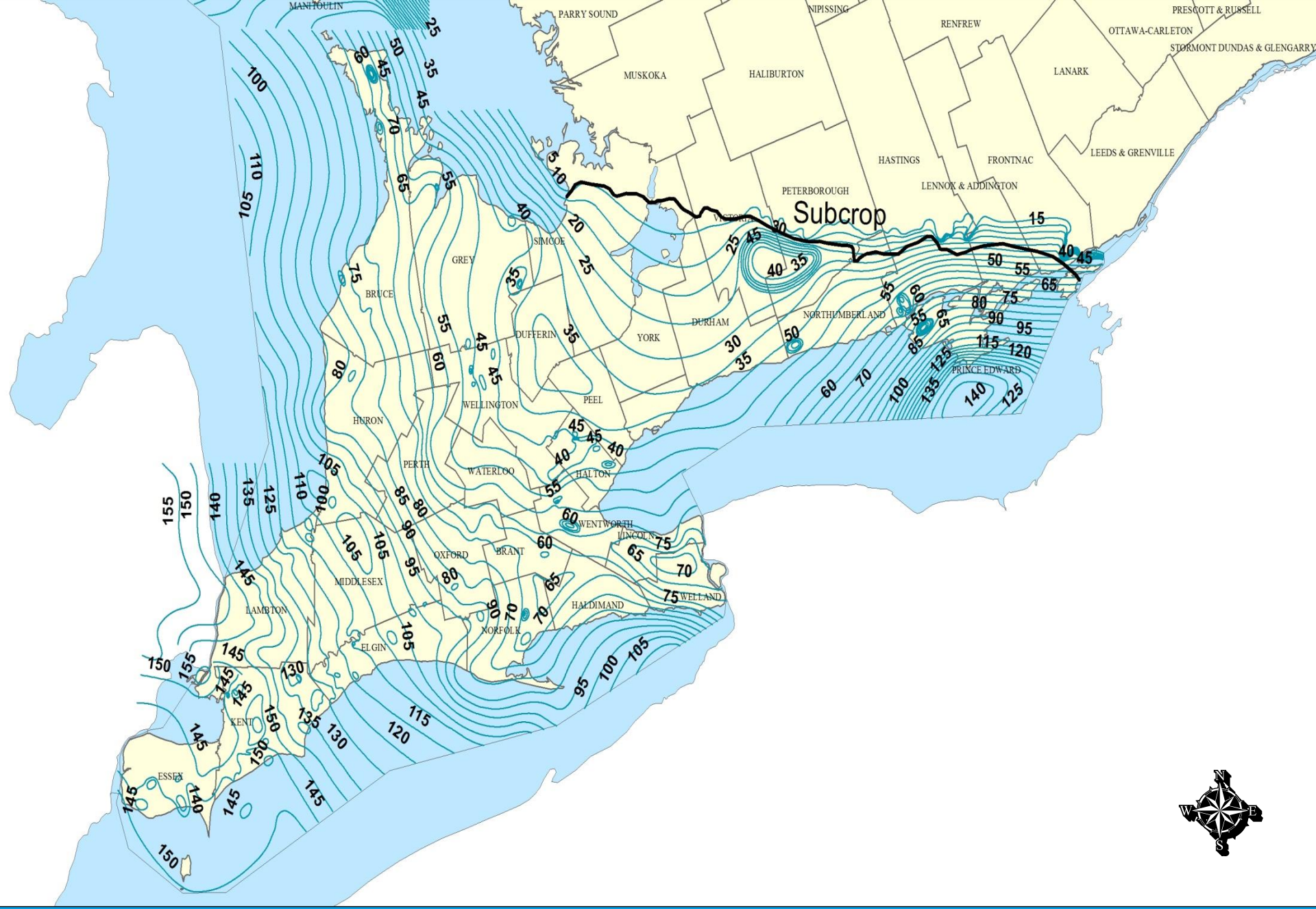
ONTARIO ORDOVICIAN POOLS AND RECOVERABLE RESERVES



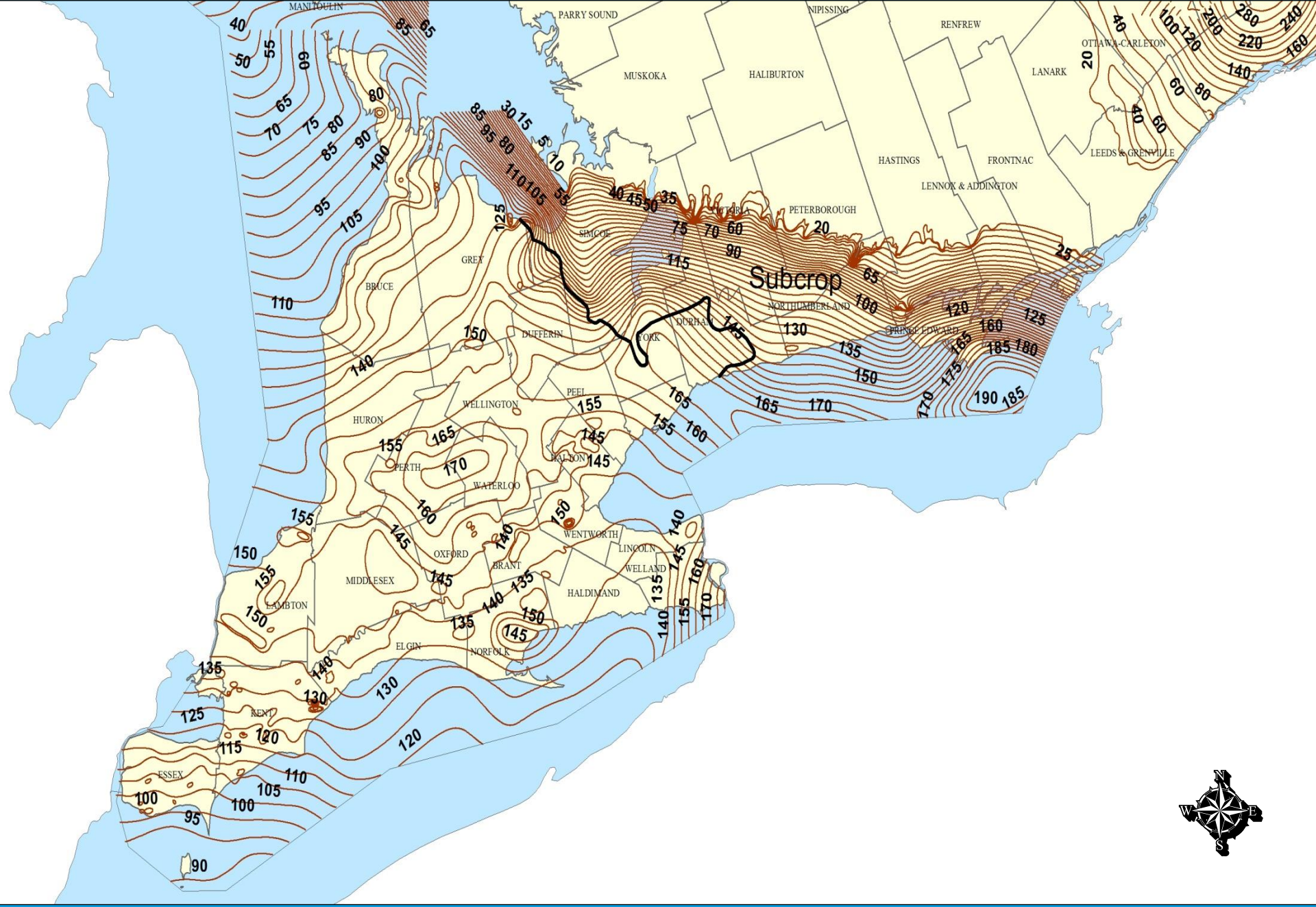

DUFFERIN
YORK
WELLINGTON
PEEL
HURON
PERTH
HALTON
WATERLOO
Algonquin Arch
WENTWORTH
OXFORD
BRANT
LINCOLN
MIDDLESEX
WELLAND
HALDIMAND
LAMBTON
NORFOLK
ELGIN
Michigan Basin
KENT
ESSEX
Findlay Arch
Appalachian Basin
Molgat and Davies, 2004
km
0
15
30
60
90
120

General Stratigraphic Section for SW Ontario



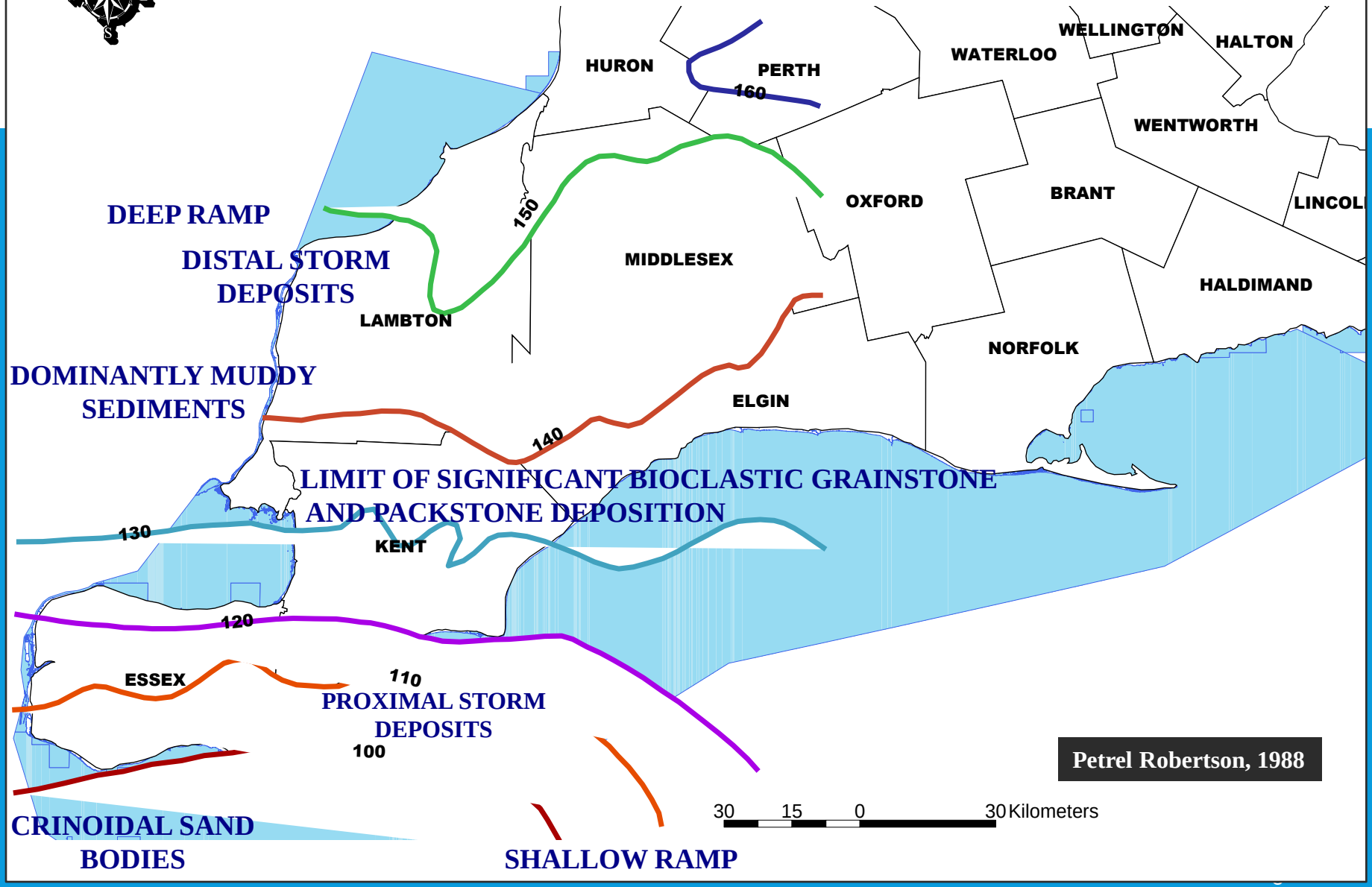


Isopach (metres) of the Black River Group. Data from Ontario Geological Survey (2011)

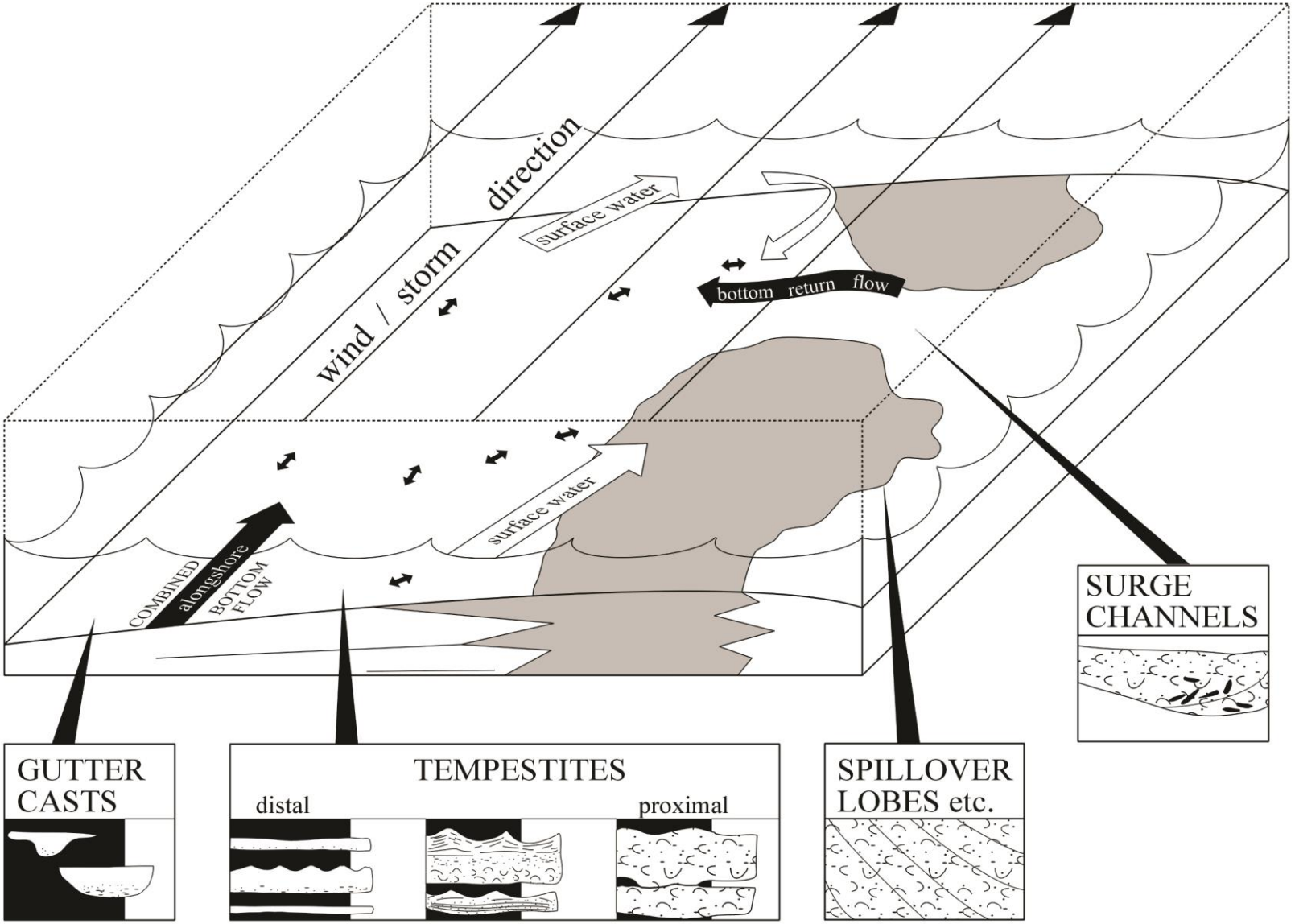


Isopach (metres) of the Trenton Group. Data from Ontario Geological Survey (2011).

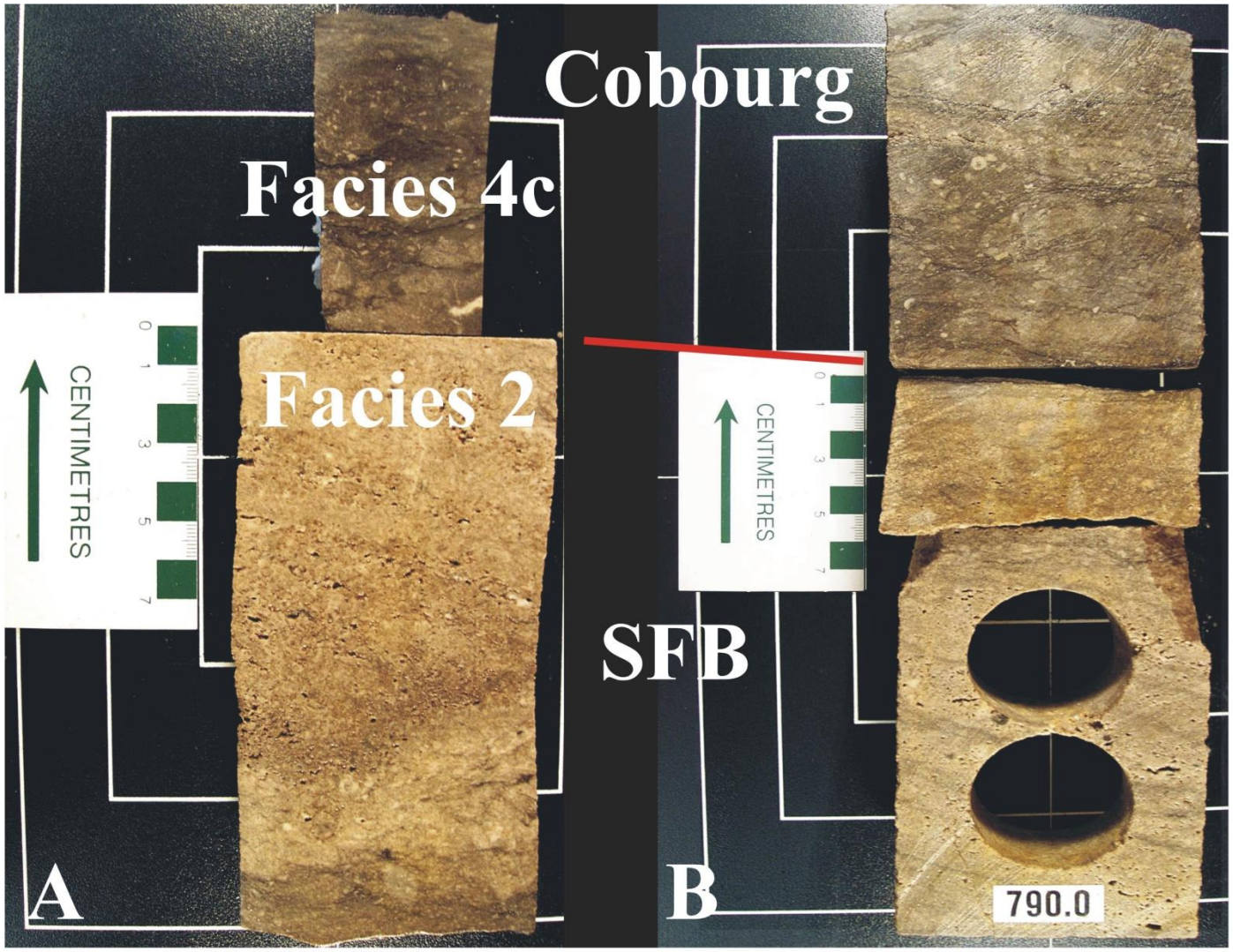
Generalized Depositional Facies Distribution of the Trenton Group Carbonates within Southwestern Ontario



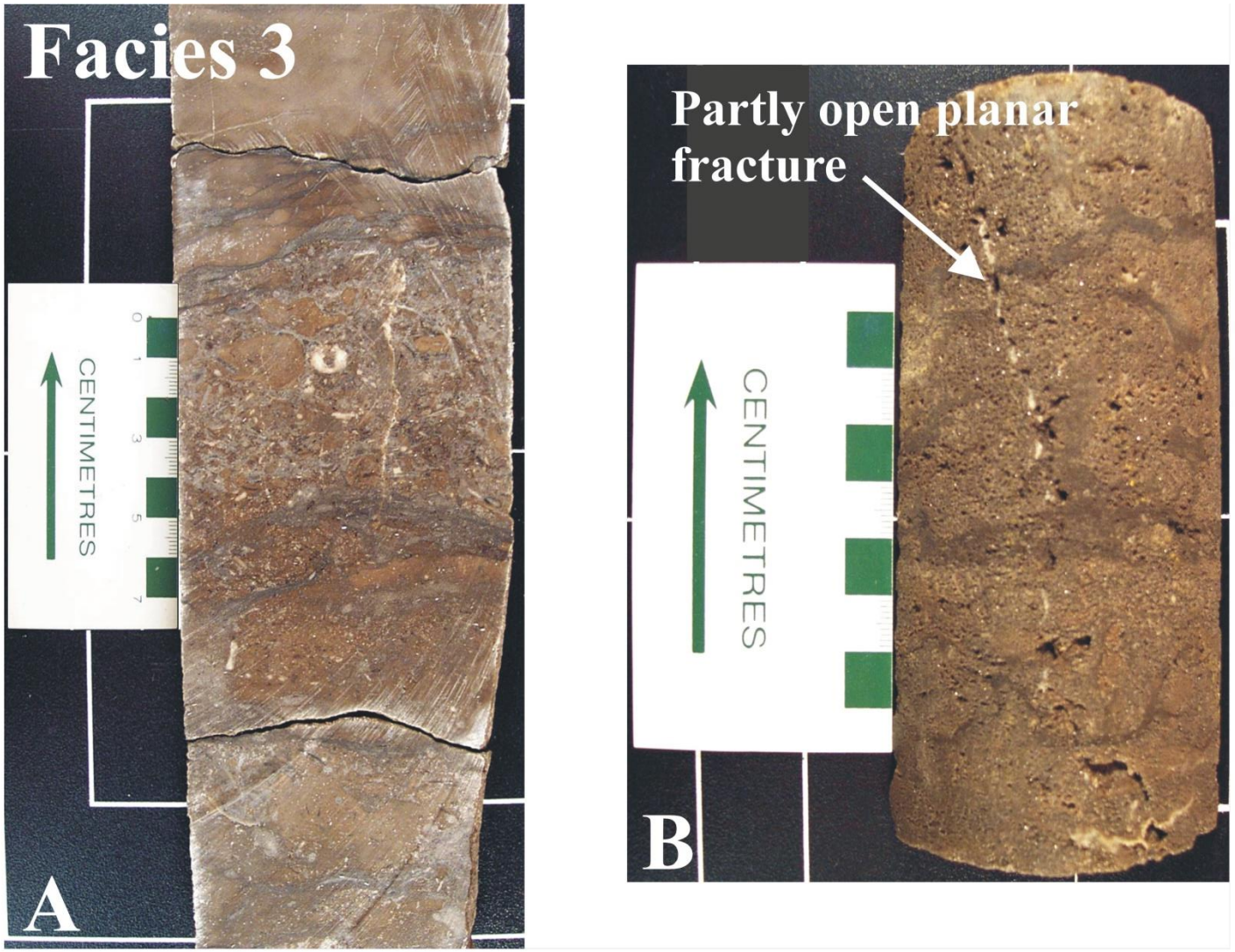
Petrel Robertson, 1988



Crinoidal Ramp Facies Model showing the ramp dynamics and resulting facies distribution (Aigner 1985)

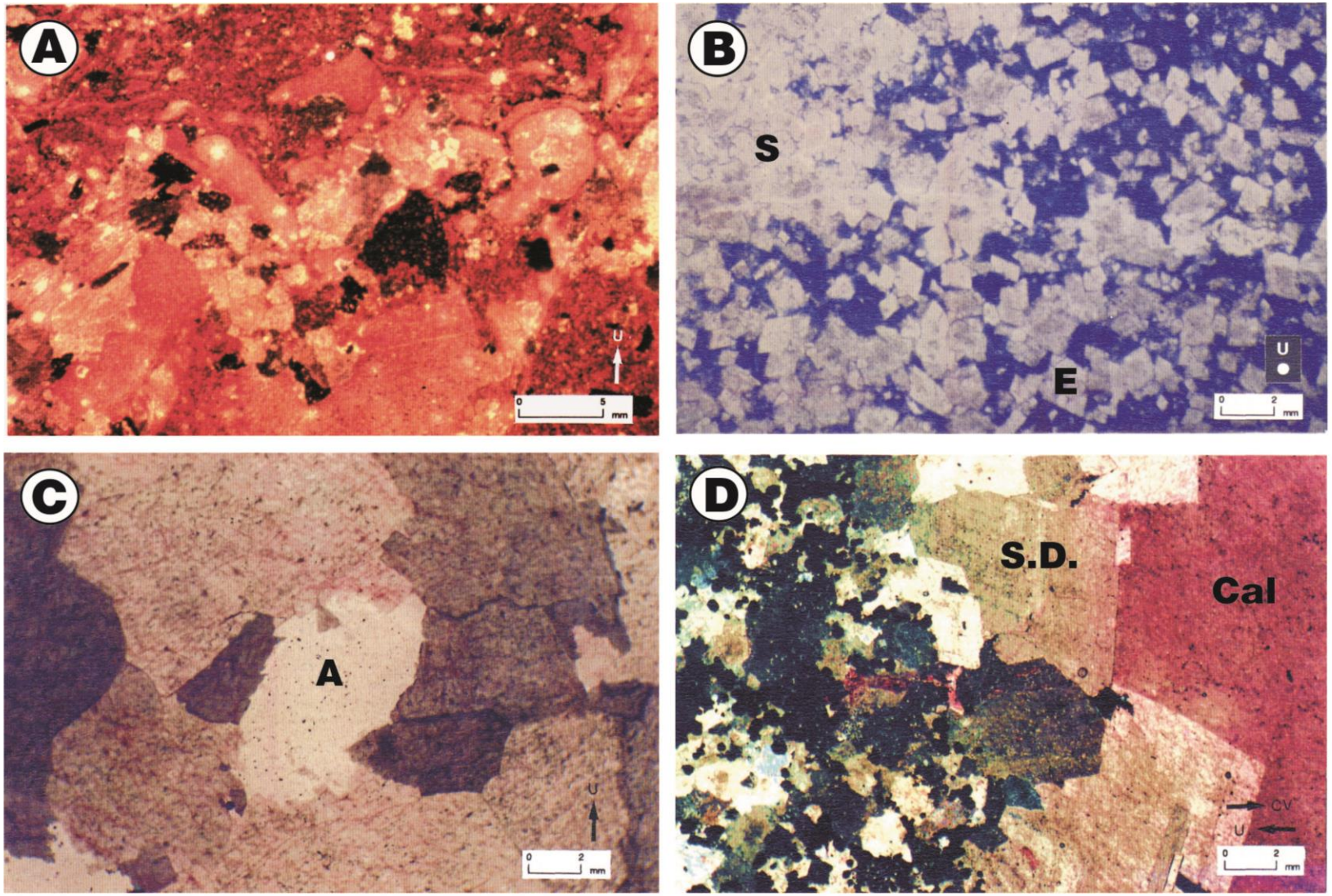


Core Photos 1A, B: Note the sharp boundary between facies 4c within the Cobourg and facies 2 at the top of the Sherman Fall Bioclastic. A) 2238 - 2238.5 feet in British American #19, Malden 4-67-VI, and B) 789.65 - 790.0 mKB in Consumers' et al Mersea 3-12-I.

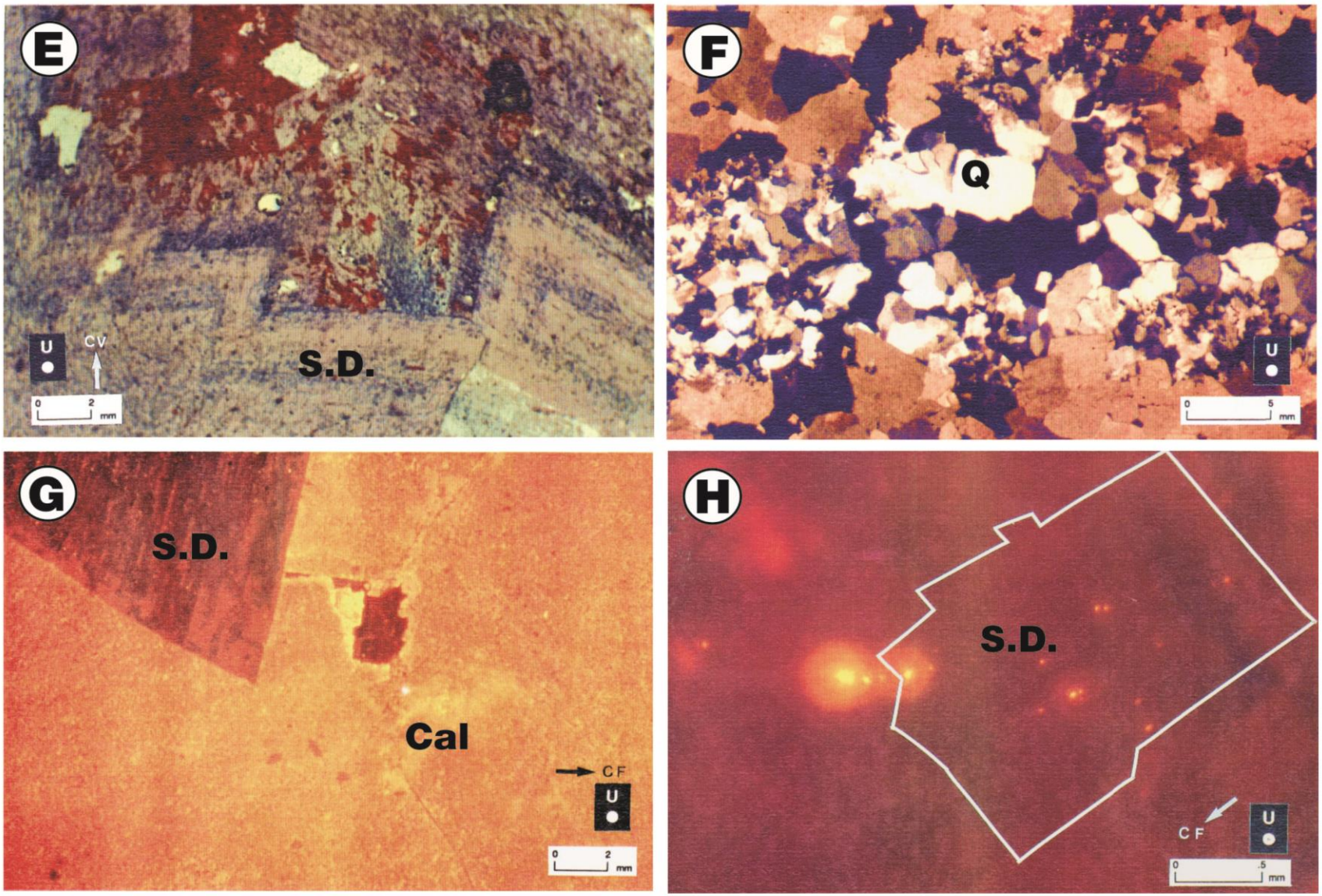


Core Photos 2 A, B: Facies 3 observed in the Coboconk Formation from A) 1012.06 to 1012.30 mKB and from B) 1017.60 to 1017.70 mKB. Note the partly open fracture (core photo B) that is lined with dolomite rhombs and partly filled with clear to white calcite cement.

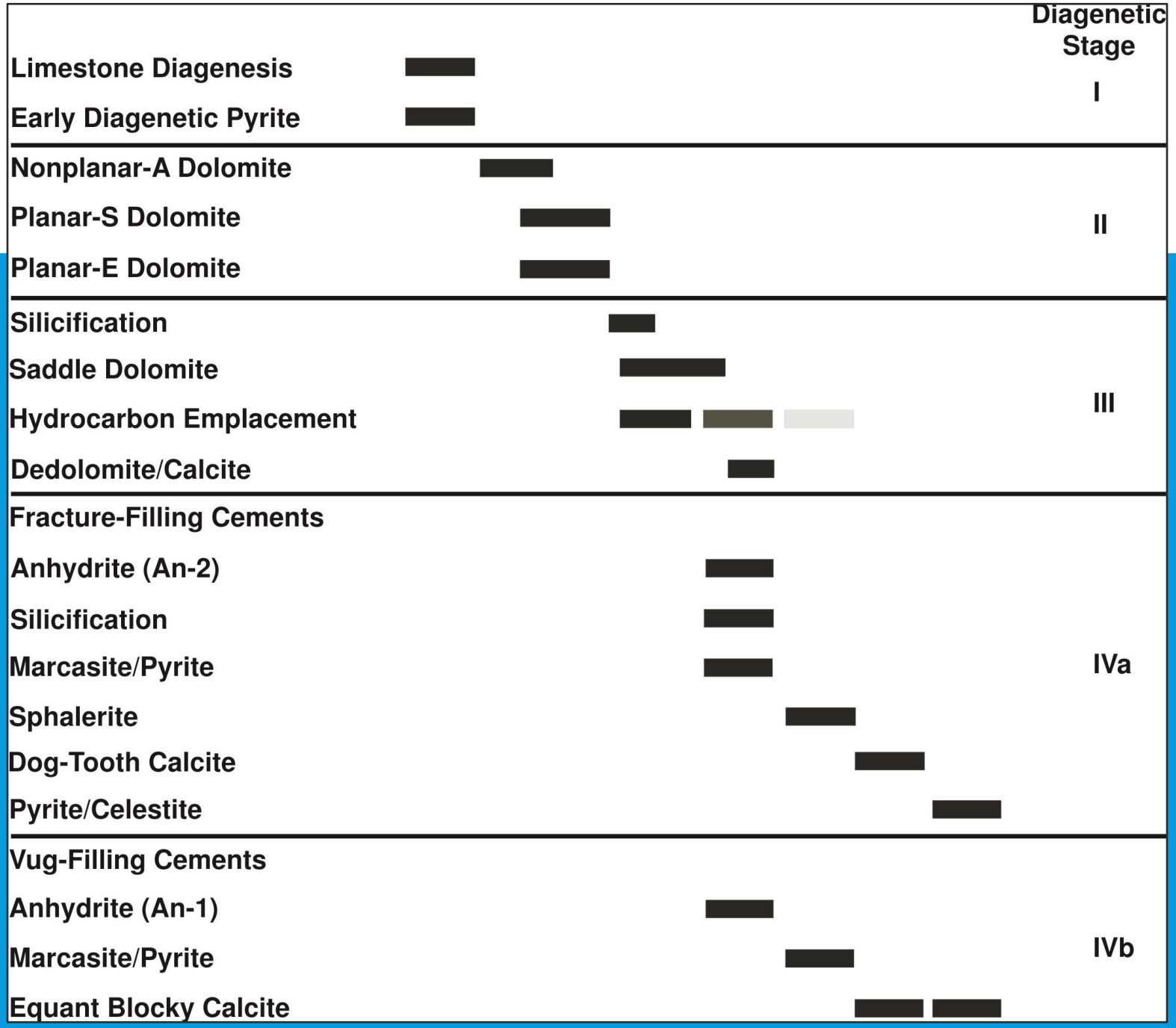
Dolomitization from relatively hot, Mg-rich fluids migrated through the regional porous Cambrian sandstone and upwards into Trenton / Black River strata, along a complex network of faults and fractures. The migrating fluids had the ability to dissolve and dolomitize the limestones and to precipitate porosity-occluding saddle dolomite, calcite and sulphides. The most pervasive dolomitization is developed in the Sherman Fall Bioclastic member because of its higher primary porosity.



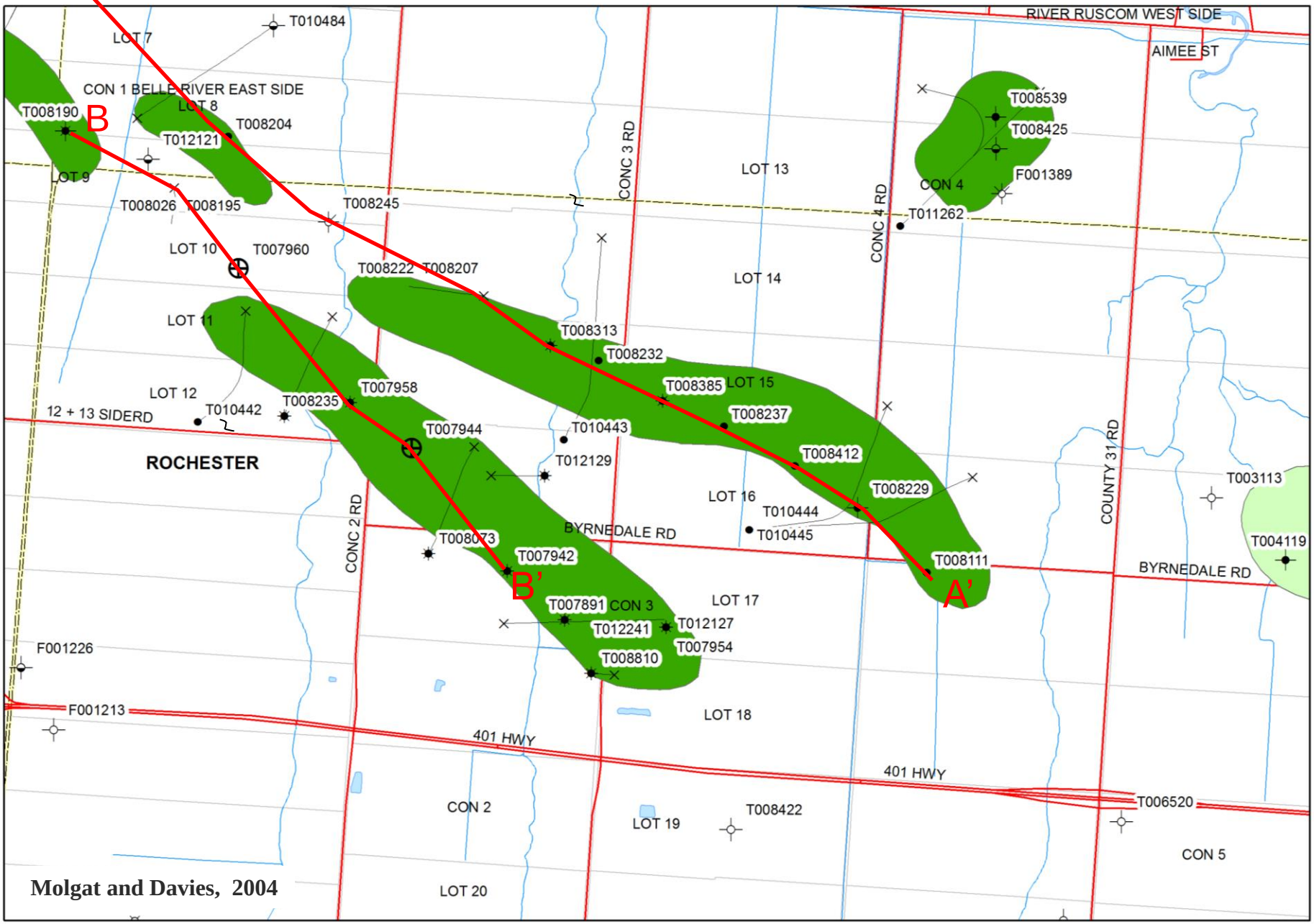
A) Photomicrograph of stained thin section under plane light. Dolomite rhombs occur interstitial to bioclastic material within the matrix. B) Photomicrograph of stained thin section under polarized light of planar-E dolomite. Note the gradation from porous planar-E dolomite (E) to finer-grained planar-S dolomite (S). C) Photomicrograph of stained thin section under plane light of nonplanar-A dolomite (A). Coarse-grained nonplanar dolomite crystals show rare development of intracrystalline porosity. D) Photomicrograph of stained section under plane light of coarse-grained, euhedral saddle dolomite (S.D.) cement (white; extinguishing grey) lining a large vug filled with equant blocky calcite (Cal) cement (red).



E) Photomicrograph of stained thin section under plane light. This example illustrates the replacement of saddle dolomite crystals to calcite with the complete infilling by calcite cement within the centre of a large vug. F) Photomicrograph of stained thin section under plane light. The coarse quartz grains increase in size toward the centre of the vug. G) Cathodoluminescence photomicrograph of a large saddle dolomite (S.D.) crystal within equant, blocky calcite (Cal) cement. H) Photomicrograph under ultraviolet fluorescence showing the boundary of earliest saddle dolomite (S.D.) cement within a fracture and fluorescence of hydrocarbons (yellow) in fluid inclusions. (U = up direction in core, CV = centre of vug, CF = centre of fracture).

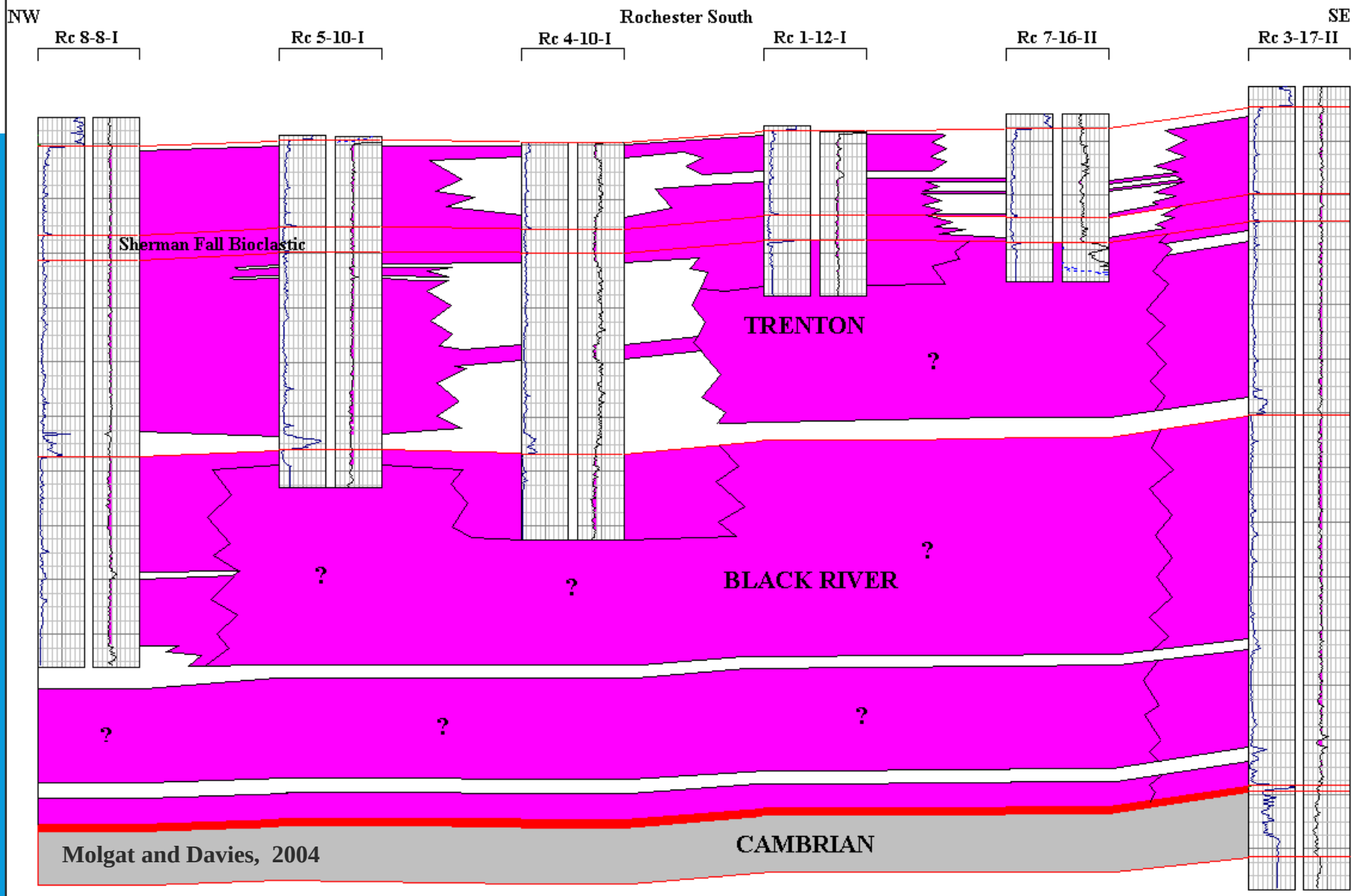

Diagenetic Stage
Limestone Diagenesis
Early Diagenetic Pyrite
I
Nonplanar-A Dolomite
Planar-S Dolomite
Planar-E Dolomite
II
Silicification
Saddle Dolomite
Hydrocarbon Emplacement
Dedolomite/Calcite
III
Fracture-Filling Cements
Anhydrite (An-2)
Silicification
Marcasite/Pyrite
Sphalerite
Dog-Tooth Calcite
Pyrite/Celestite
IVa
Vug-Filling Cements
Anhydrite (An-1)
Marcasite/Pyrite
Equant Blocky Calcite
IVb

CROSS SECTIONS

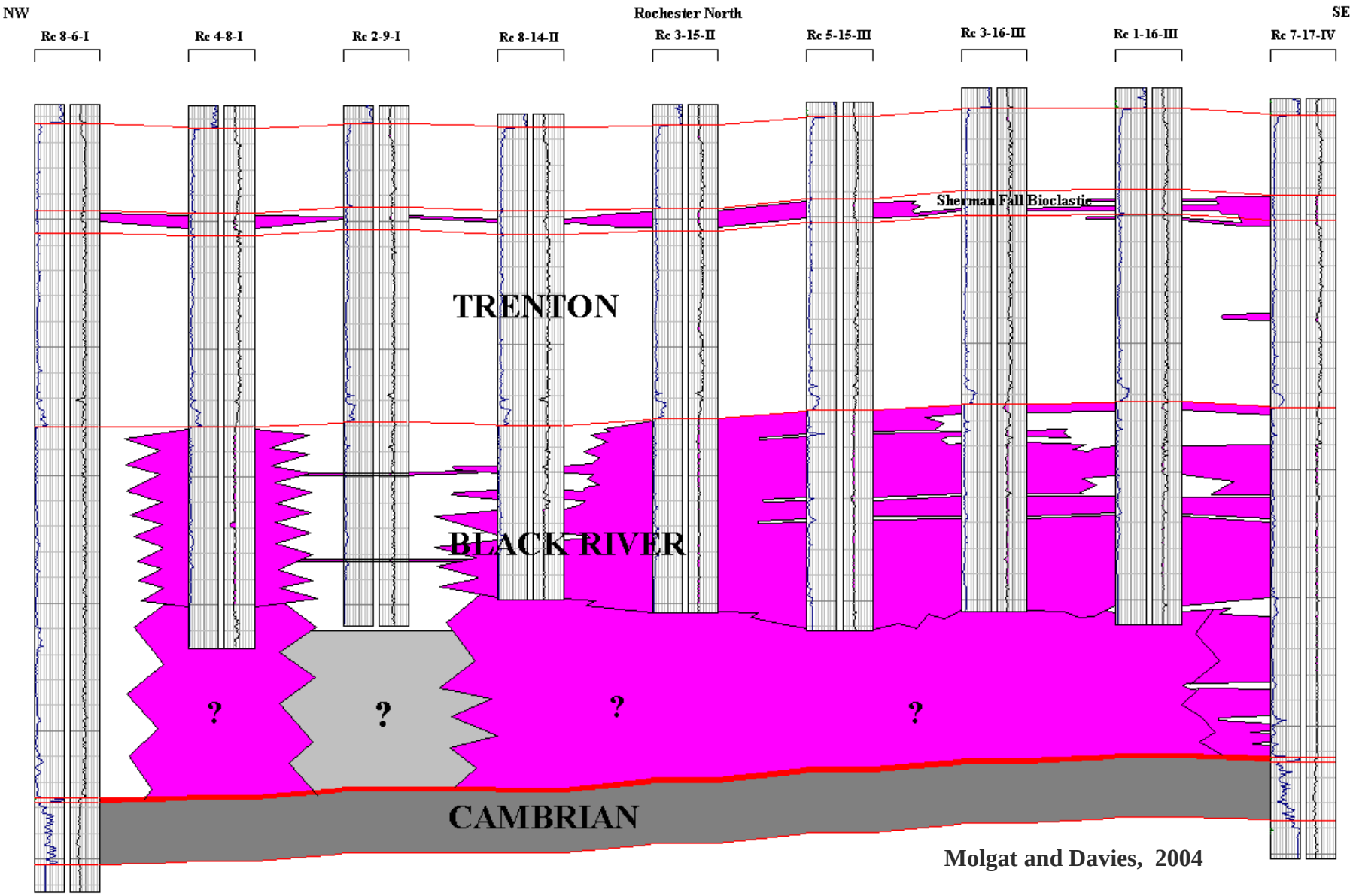


Molgat and Davies, 2004

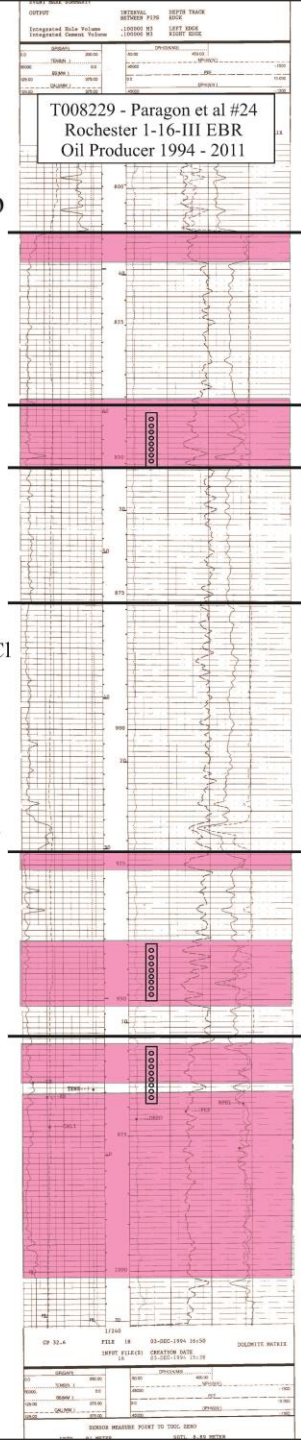
Rochester South, B-B' longitudinal cross-section showing dolomite distribution



Rochester North, A-A' longitudinal cross-section showing dolomite distribution



Molgat and Davies, 2004



Trenton Group

Cobourg

Cased and cemented to 1010 mKB
PBTD 945 mKB
Completed in SFB and Gull River
Perfed and acidized
841.6 - 851 mKB in SFB and
958.5 - 969 mKB in Gull River
Pressure 7338 kPa (1064 psi)
no production results given

Sherman Fall Bioclastic

Sherman Fall Argillaceous

May 2002 reperfed 939.8 to 950.8 mKB
acidized with 10.3 m3 (65 bbls) of 28% HCl
recovery 5.2 m3 oil in 9 hrs (30 bbls)

Kirkfield

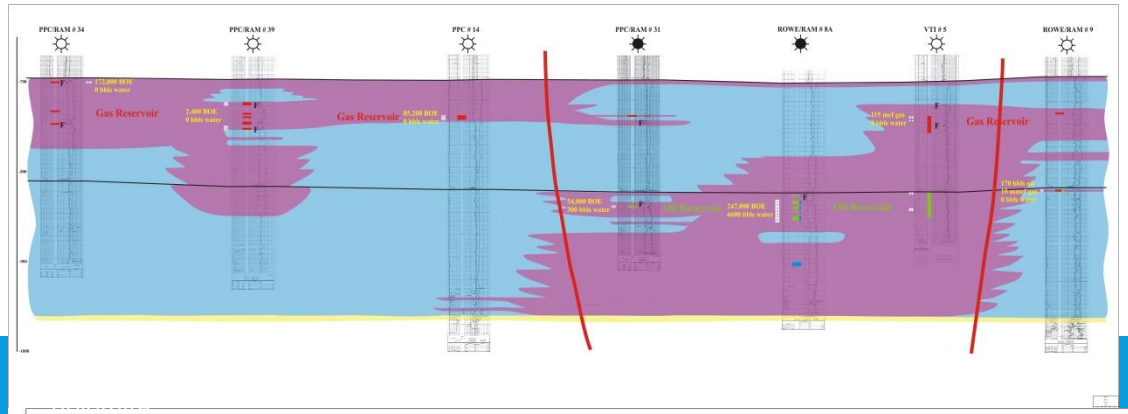
Black River Group

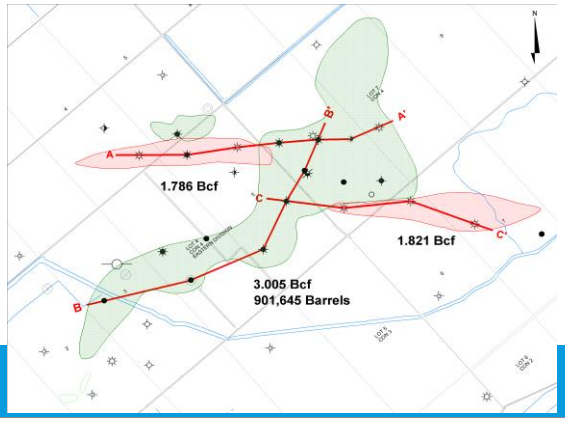
Coboconk

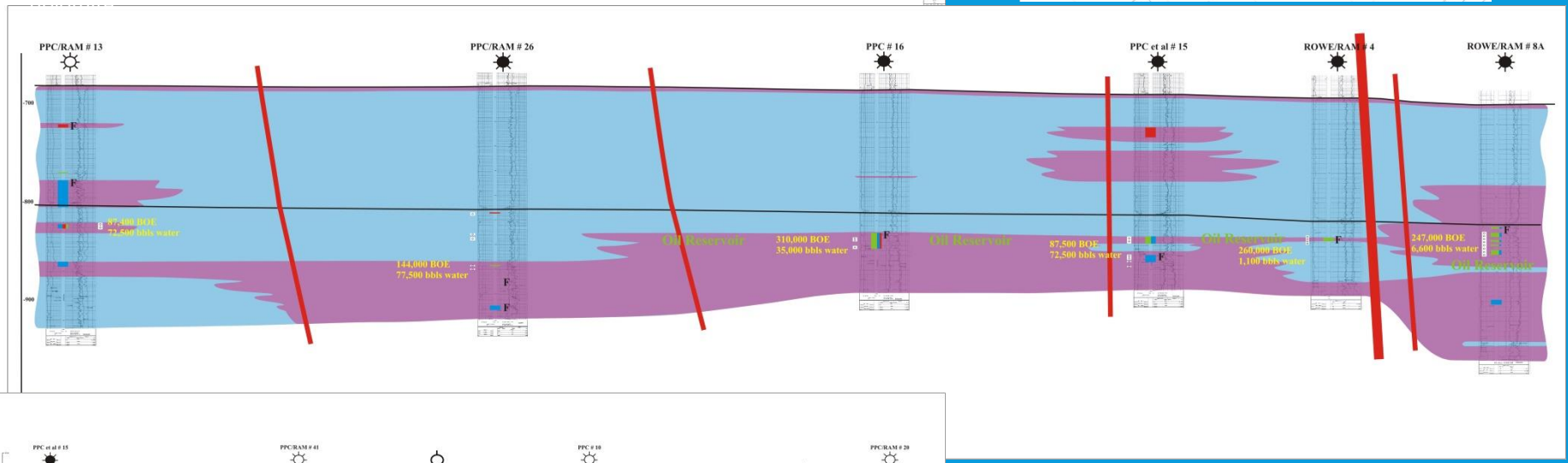
DST #1: 937-953 mKB (10, 60, 90, 120)
IHP: 10,416 kPa ; ISIP: 9534 kPa
FHP: 10,407 kPa' FSIP: 9261 kPa
PF: WAB increasing slightly
VO: WIP increasing to FAB @ 30 min, steady
NGTS, Recovery 10 m SGCO

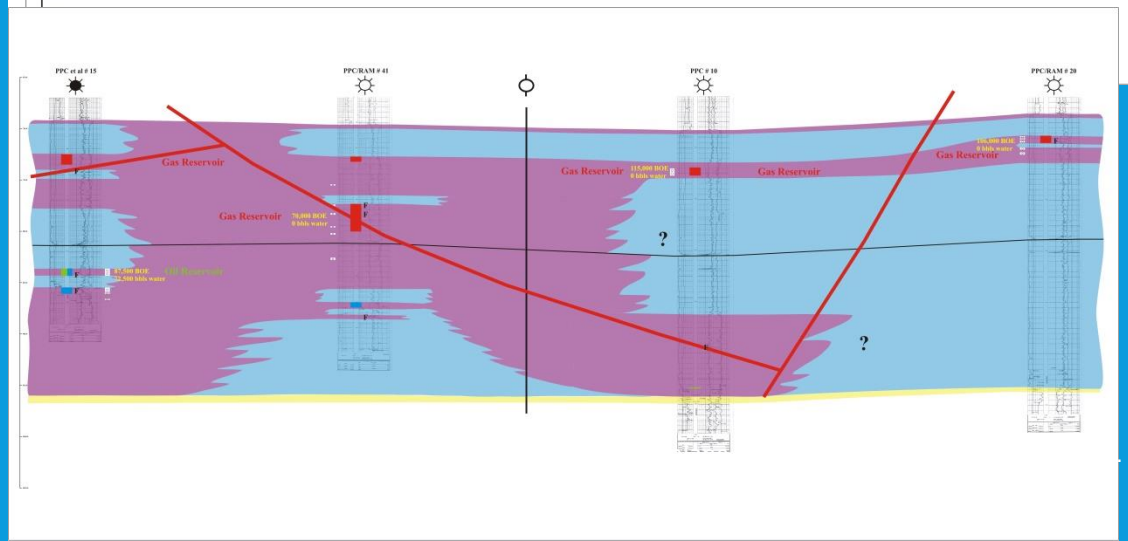
Gull River

DST #2: 956 to 983 mKB (10, 60, 90, 420)
IHP: 10,629 kPa, ISIP: 9564 kPa
FHP: 10,570 kPa, FSIP: 9457 kPa
PF: FIP increasing to strong in 30 seconds, steady
VO: GTS in 17 minutes; 234 m3/d in 90 min
Recovery: 30 m of GO (40 API) and 86 m DF









Dover 7-5-VE Oil Pool
Dover Township, Kent County
1983 – E.P. Rowe and Ram Petroleum
1.35 mmbbls oil and 10.3 bcf gas

Colquhoun and Johnston , 2004

South Pool

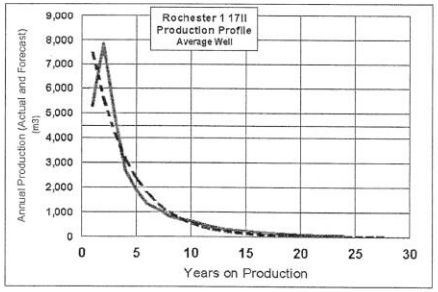
Rochester 1-17-II EBR
Average Well

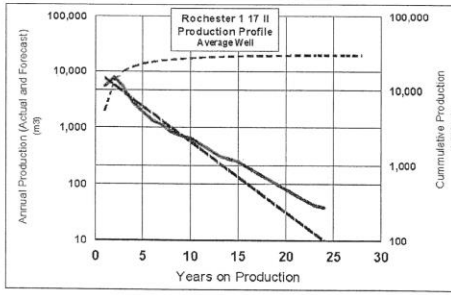
GOR: 475
WOR: 0.484

Prod Year	Oil m3	Gas e3m3	H2O m3	Cum Oil	Cum Gas	Cum Wtr	GOR
1	7,500	3,563	3,629	7,500	3,563	3,629	475
2	5,625	2,672	2,722	13,125	6,234	6,351	475
3	4,219	2,004	2,041	17,344	8,238	8,392	475
4	3,164	1,503	1,531	20,508	9,741	9,923	475
5	2,373	1,127	1,148	22,881	10,868	11,072	475
6	1,780	845	861	24,661	11,714	11,933	475
7	1,335	634	646	25,995	12,348	12,579	475
8	1,001	476	484	26,997	12,823	13,063	475
9	751	357	363	27,747	13,180	13,427	475
10	563	267	272	28,311	13,448	13,699	475
11	422	201	204	28,733	13,648	13,903	475
12	317	150	153	29,050	13,799	14,057	475
13	238	113	115	29,287	13,911	14,172	475
14	178	85	86	29,465	13,996	14,258	475
15	134	63	65	29,599	14,060	14,322	475
16	100	48	48	29,699	14,107	14,371	475
17	75	36	36	29,774	14,143	14,407	475
18	56	27	27	29,831	14,170	14,435	475
19	42	20	20	29,873	14,190	14,455	475
20	32	15	15	29,905	14,205	14,470	475
21	24	11	12	29,929	14,216	14,482	475
22	18	8	9	29,946	14,225	14,491	475
23	13	6	6	29,960	14,231	14,497	475
24	10	5	5	29,970	14,236	14,502	475
25	8	4	4	29,977	14,239	14,506	475
26	6	3	3	29,983	14,242	14,508	475
27	4	2	2	29,987	14,244	14,510	475
28	3	2	2	29,990	14,245	14,512	475
29	2	1	1	29,993	14,247	14,513	475
30	2	1	1	29,995	14,247	14,514	475
31	1	1	1	29,996	14,248	14,515	475
32	1	0	0	29,997	14,249	14,515	475
	29,997	14,249	14,515				

Average Well Oil		
Start:	7500	m3 per year
Decline Rate:	25.0%	per year
Decline Fact:	0.0237	per month
Recovery	29,997	m3

29,930
29,997





Revised May 27th 2004

North Pool

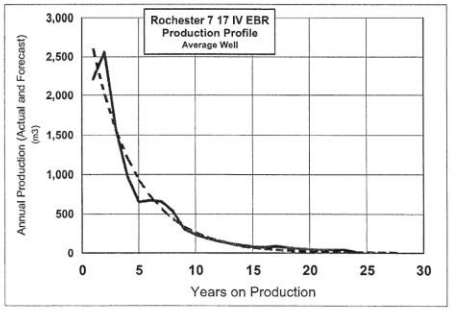
Rochester 7-17-IV EBR
Average Well

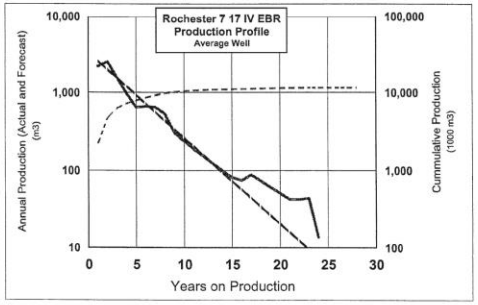
GOR: 450
WOR: 0.834

Prod Year	Oil m3	Gas e3m3	H2O m3	Cum Oil	Cum Gas	Cum Wtr	GOR
1	2,600	1,170	2,169	2,600	1,170	2,169	450
2	2,015	907	1,681	4,615	2,077	3,851	450
3	1,562	703	1,303	6,177	2,779	5,153	450
4	1,210	545	1,010	7,387	3,324	6,163	450
5	938	422	783	8,325	3,746	6,946	450
6	727	327	606	9,052	4,073	7,552	450
7	563	254	470	9,615	4,327	8,022	450
8	437	196	364	10,052	4,523	8,387	450
9	338	152	282	10,390	4,676	8,669	450
10	262	118	219	10,652	4,794	8,888	450
11	203	91	170	10,856	4,885	9,057	450
12	158	71	131	11,013	4,956	9,189	450
13	122	55	102	11,135	5,011	9,291	450
14	95	43	79	11,230	5,053	9,369	450
15	73	33	61	11,303	5,086	9,431	450
16	57	26	47	11,360	5,112	9,478	450
17	44	20	37	11,404	5,132	9,515	450
18	34	15	28	11,438	5,147	9,543	450
19	26	12	22	11,464	5,159	9,565	450
20	20	9	17	11,485	5,168	9,582	450
21	16	7	13	11,501	5,175	9,596	450
22	12	6	10	11,513	5,181	9,606	450
23	10	4	8	11,523	5,185	9,614	450
24	7	3	6	11,530	5,189	9,620	450
25	6	3	5	11,536	5,191	9,625	450
26	4	2	4	11,540	5,193	9,629	450
27	3	2	3	11,544	5,195	9,631	450
28	3	1	2	11,546	5,196	9,634	450
29	2	1	2	11,548	5,197	9,635	450
30	2	1	1	11,550	5,198	9,637	450
31	1	1	1	11,551	5,198	9,638	450
32	1	0	1	11,552	5,199	9,639	450
	11,552	5,199	9,639				

Average Well Oil		
Start:	2600	m3 per year
Decline Rate:	22.5%	per year
Decline Fact:	0.0210	per month
Recovery	11,552	m3

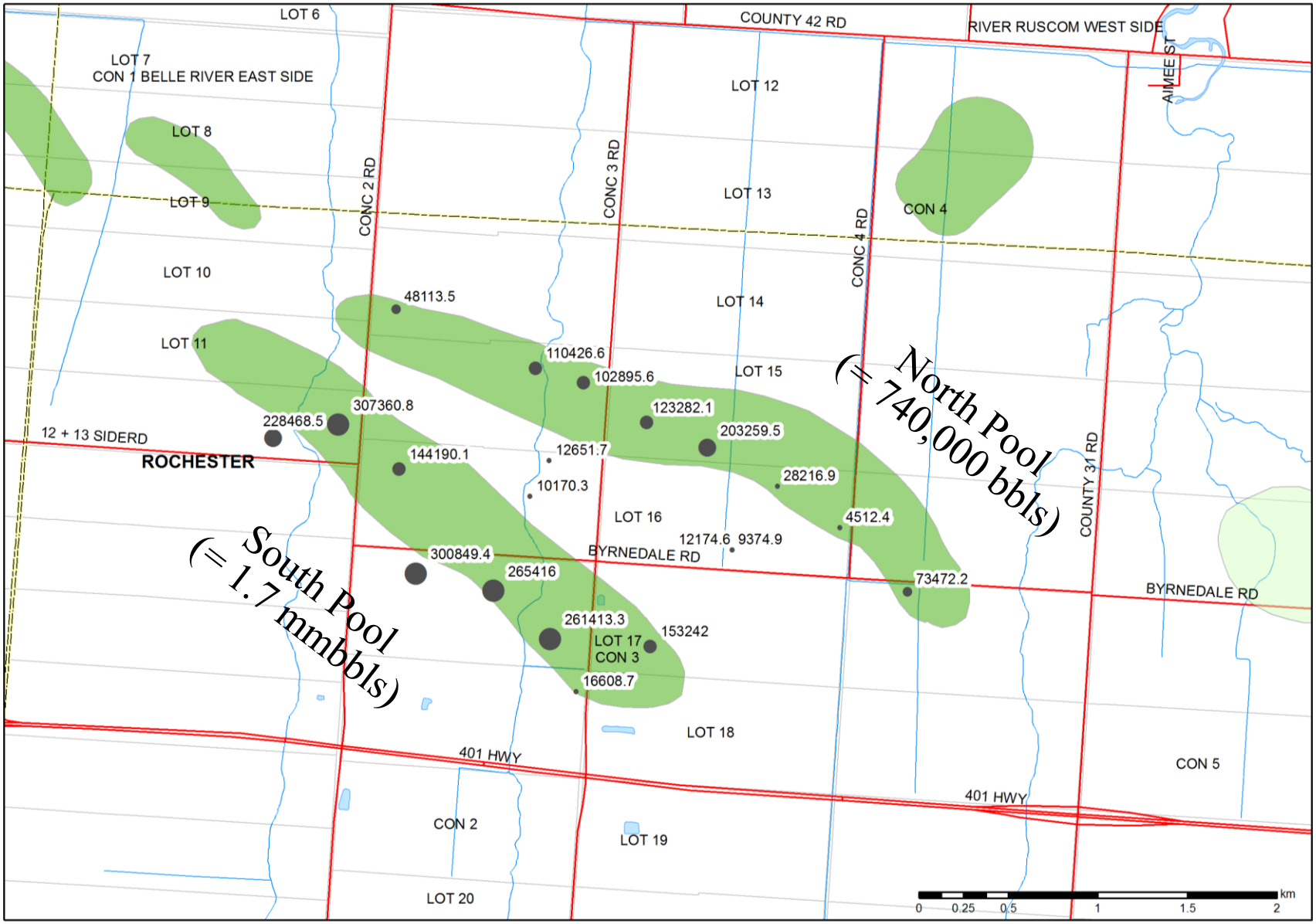
11,516

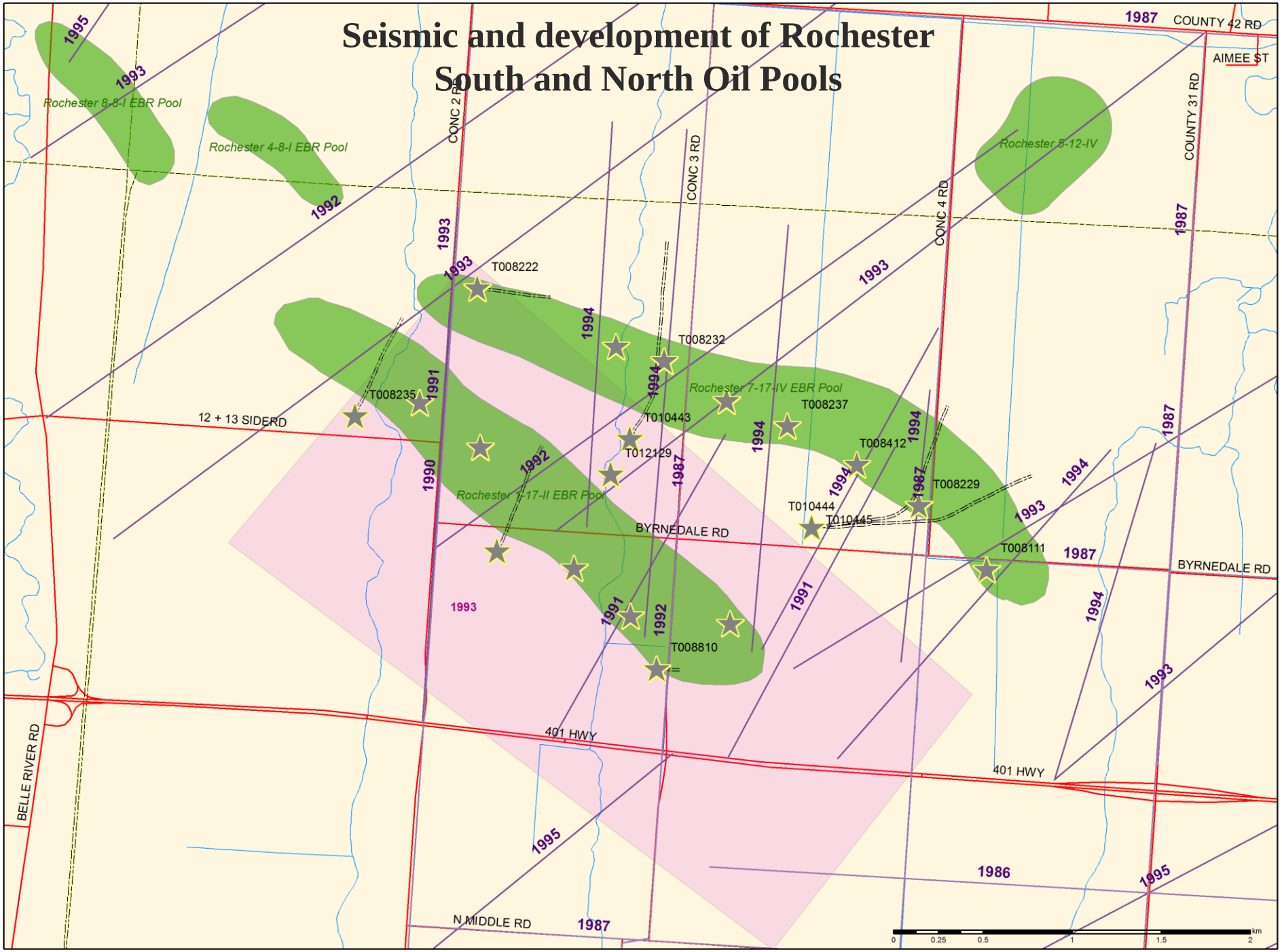


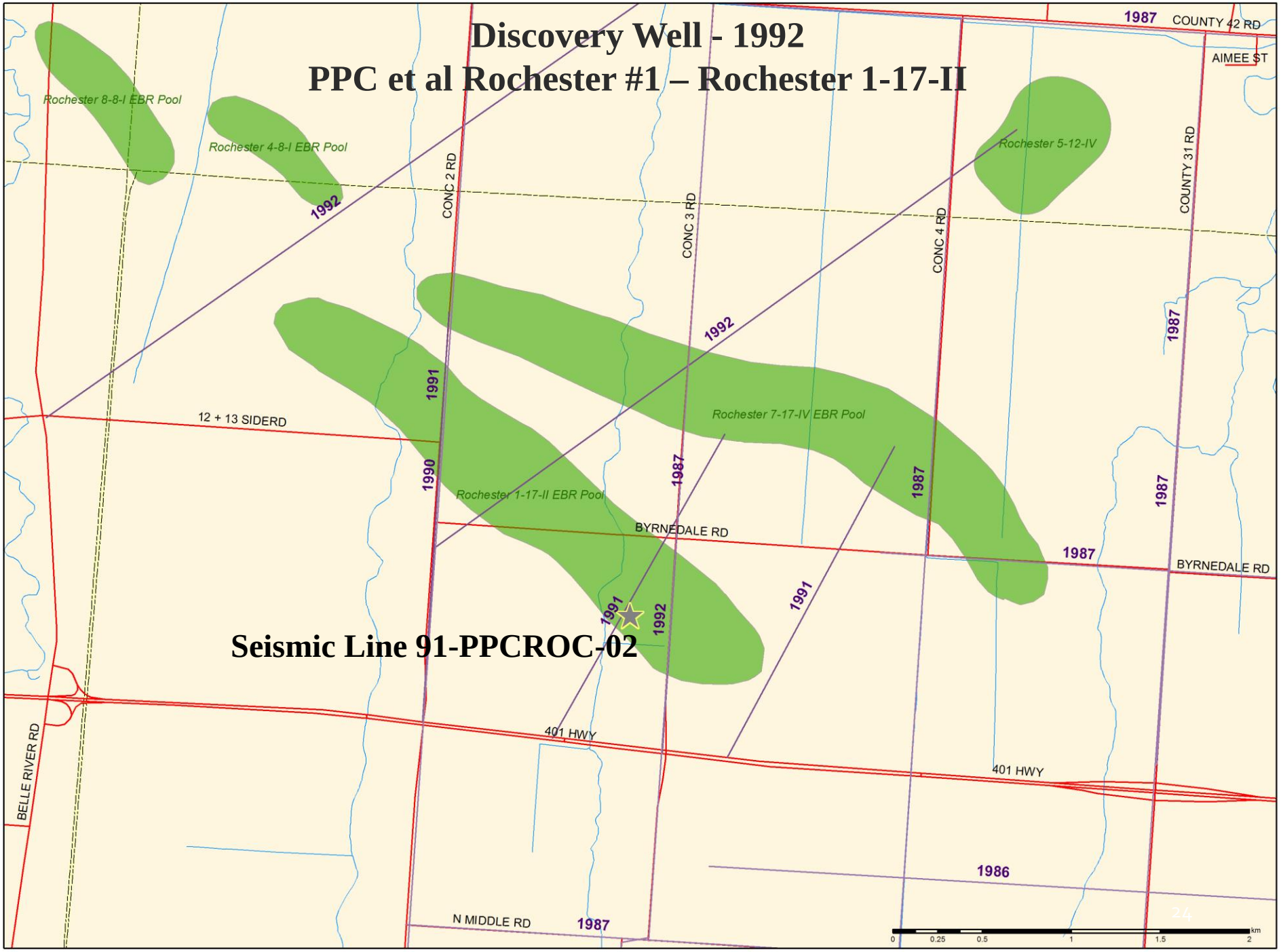


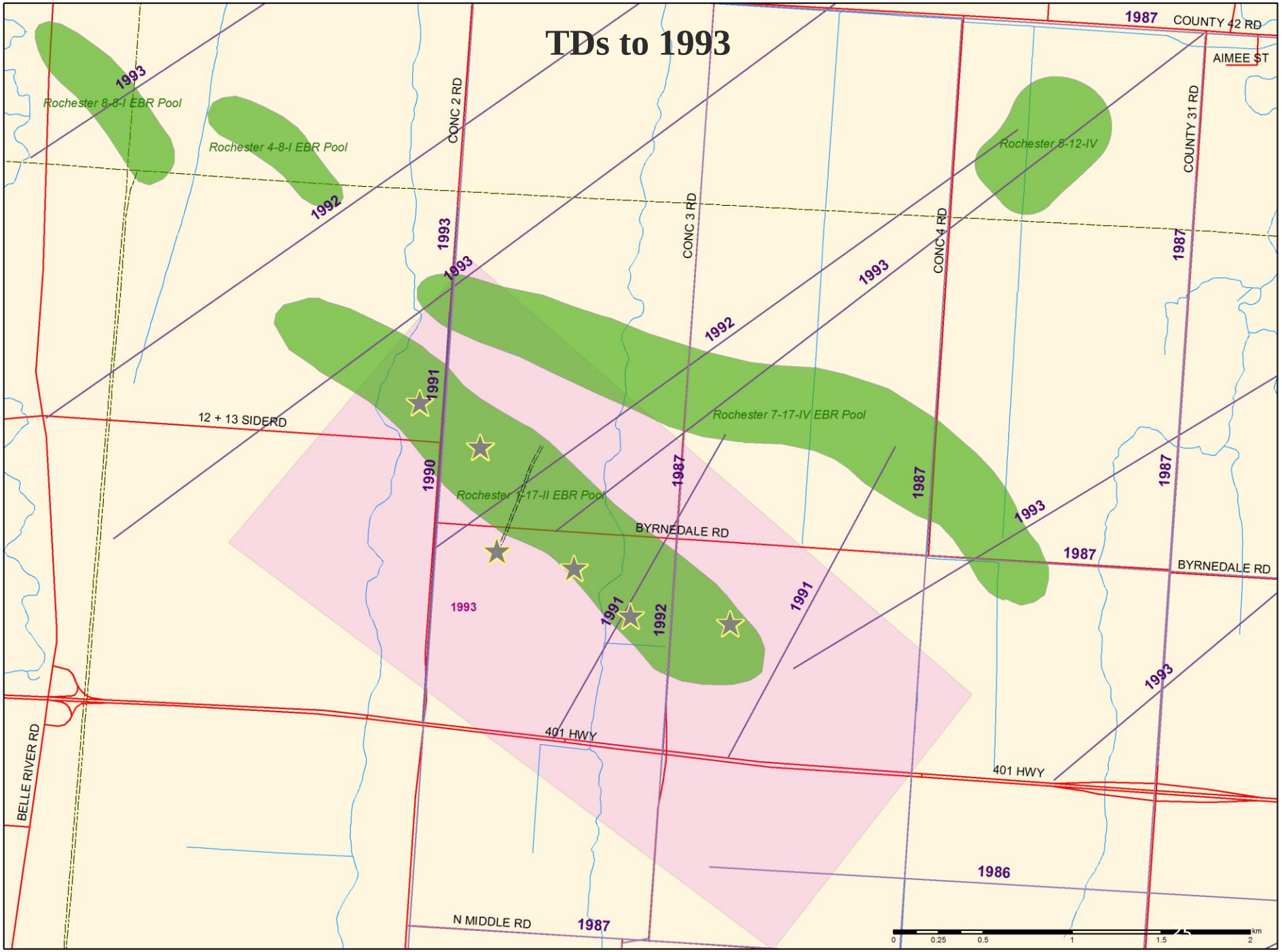
Production profiles for average Trenton-Black River oil wells at Rochester (Golder 2005) Rochester 1-17-II in Rochester South Oil Pool; Rochester 7-17-IV in Rochester North Oil Pool

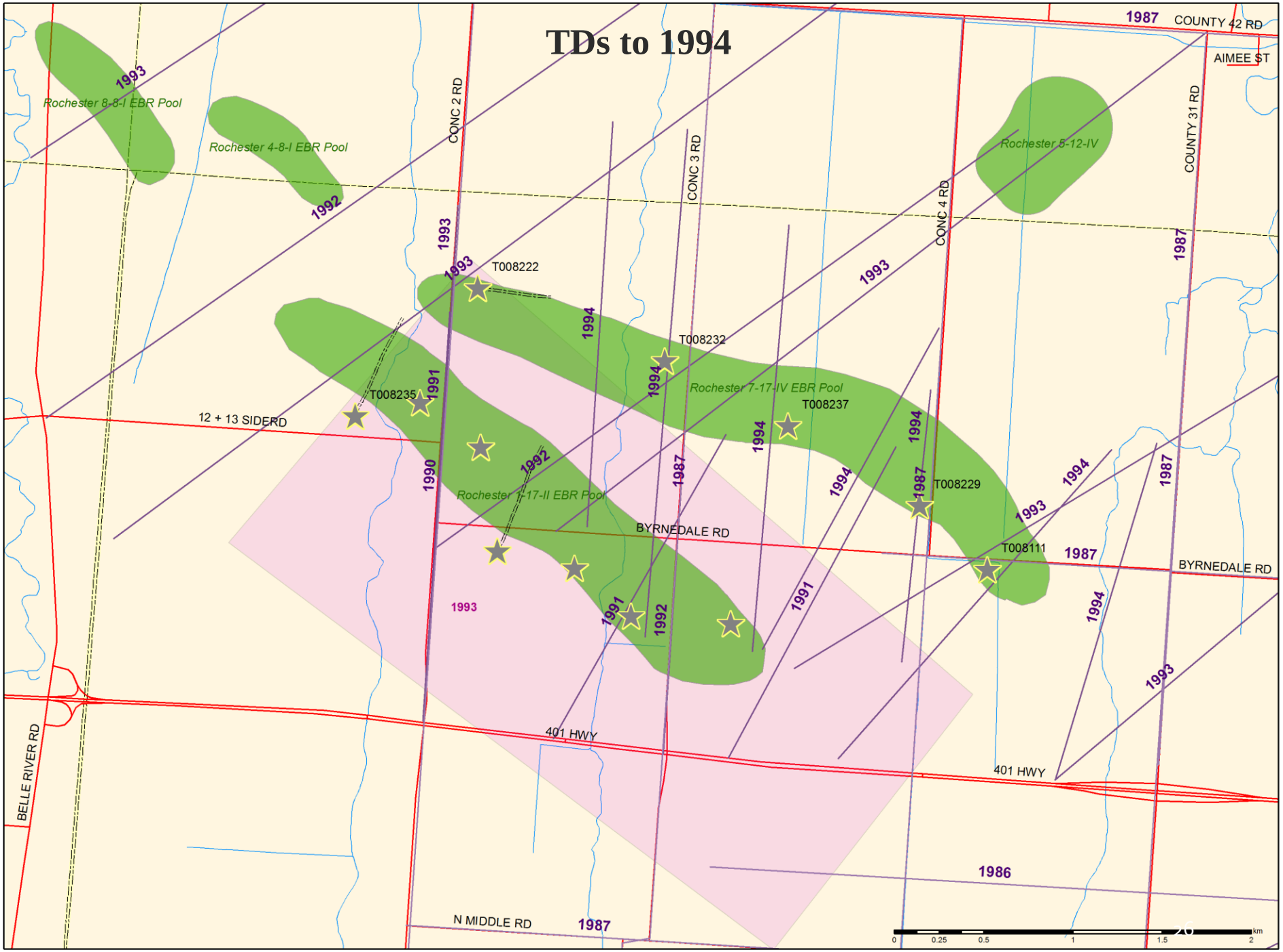
Cumulative Oil Production (bbls) to 2015

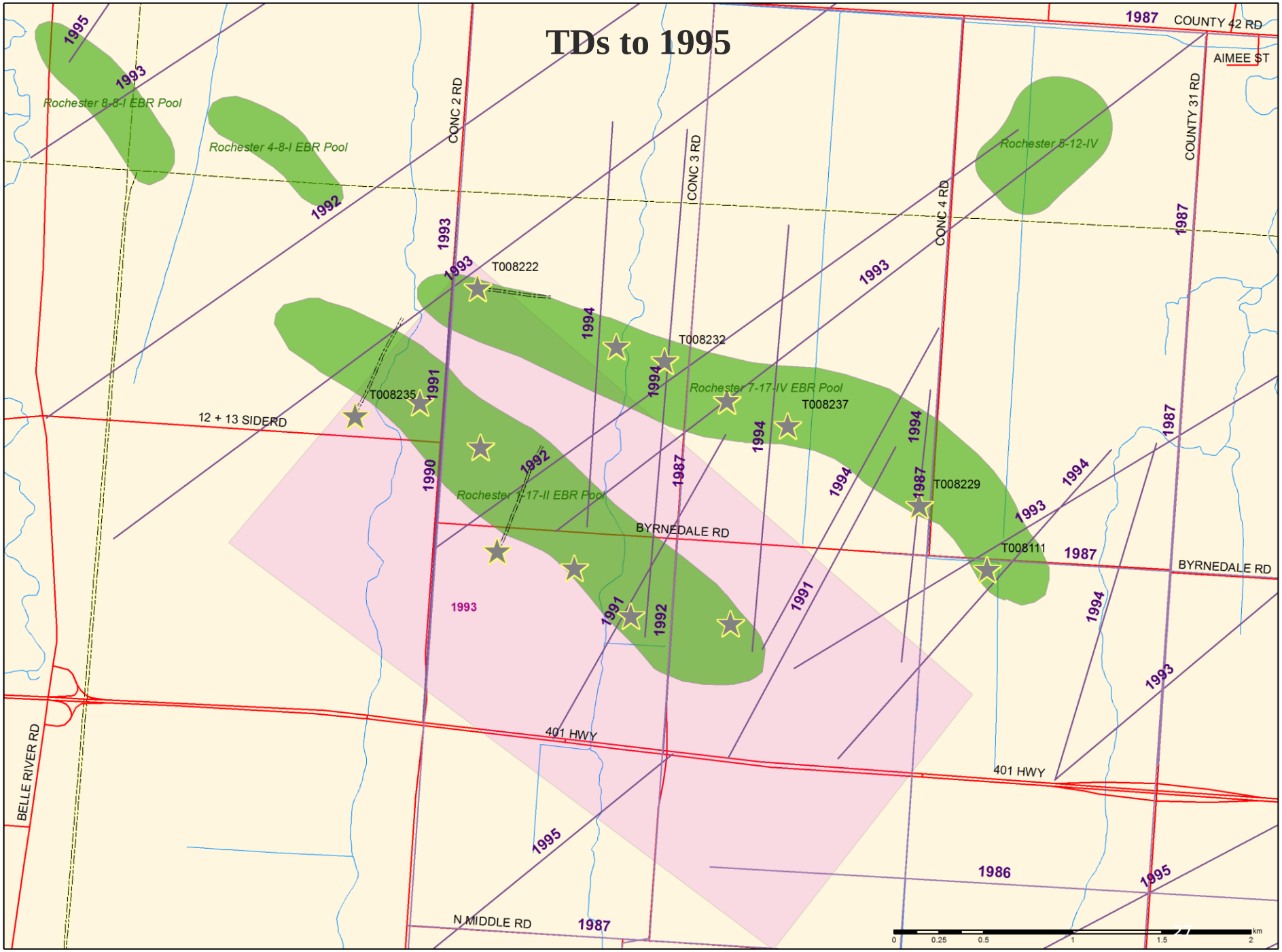


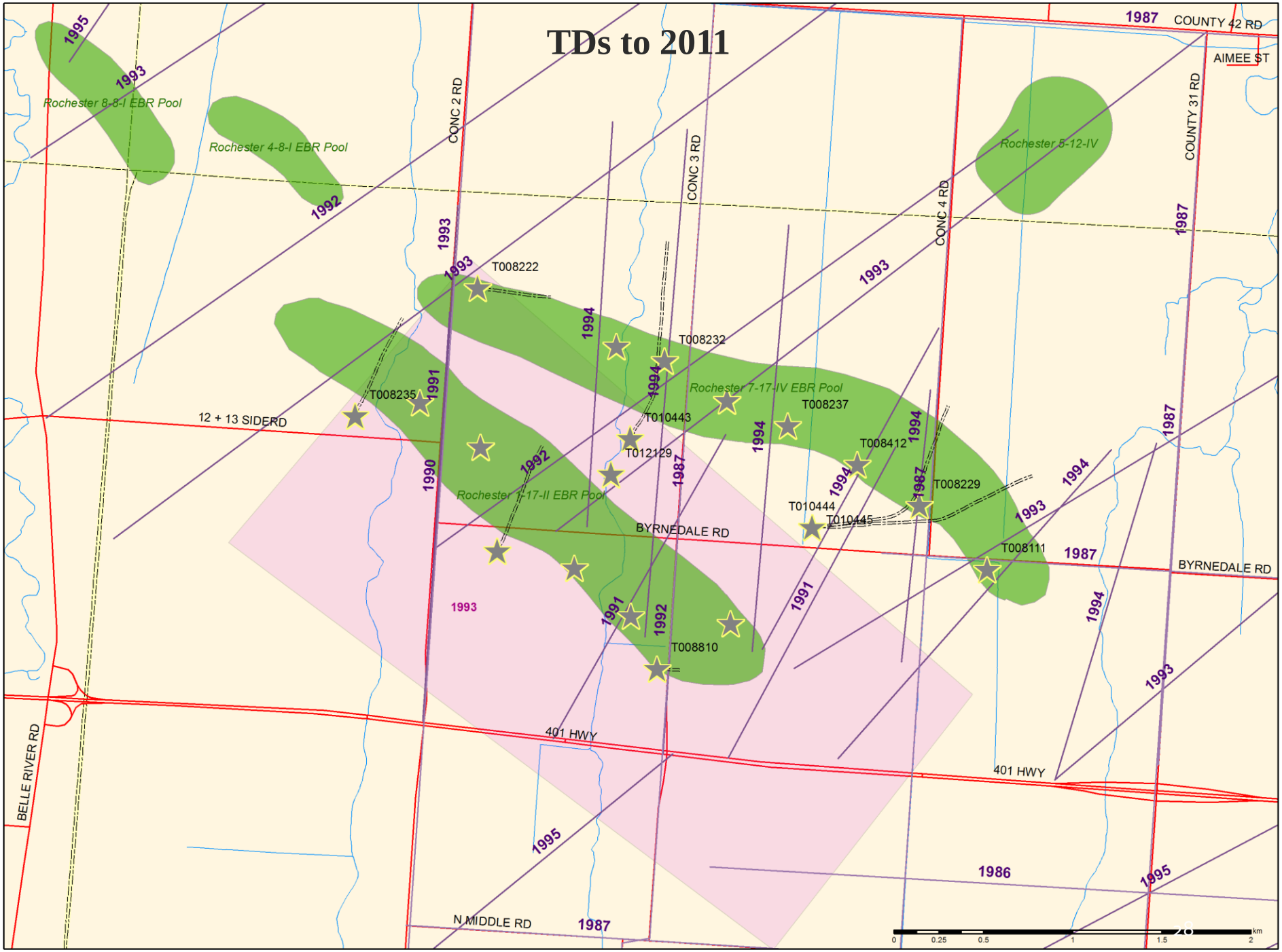

Seismic and development of Rochester South and North Oil Pools
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
Rochester 5-12-IV
Rochester 7-17-IV EBR Pool
Rochester 7-17-II EBR Pool
T008222
T008232
T008235
T008237
T010443
T012129
T008412
T008229
T010444
T010445
T008111
T008810
1993
12 + 13 SIDERD
BYRNEDALE RD
401 HWY
N MIDDLE RD
BELLE RIVER RD
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 42 RD
COUNTY 31 RD
AIMEE ST
0
0.25
0.5
1
1.5
2
km


Discovery Well - 1992
PPC et al Rochester #1 – Rochester 1-17-II
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
Rochester 5-12-IV
Rochester 7-17-IV EBR Pool
Rochester 1-17-II EBR Pool
Seismic Line 91-PPCROC-02
1987 COUNTY 42 RD
AIMEE ST
1992
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 31 RD
1987
1991
12 + 13 SIDERD
1990
1987
1987
1987
BYRNEDALE RD
1987
BYRNEDALE RD
1991
1991
1992
401 HWY
401 HWY
BELLE RIVER RD
1986
N MIDDLE RD
1987
0
0.25
0.5
1
1.5
2
km

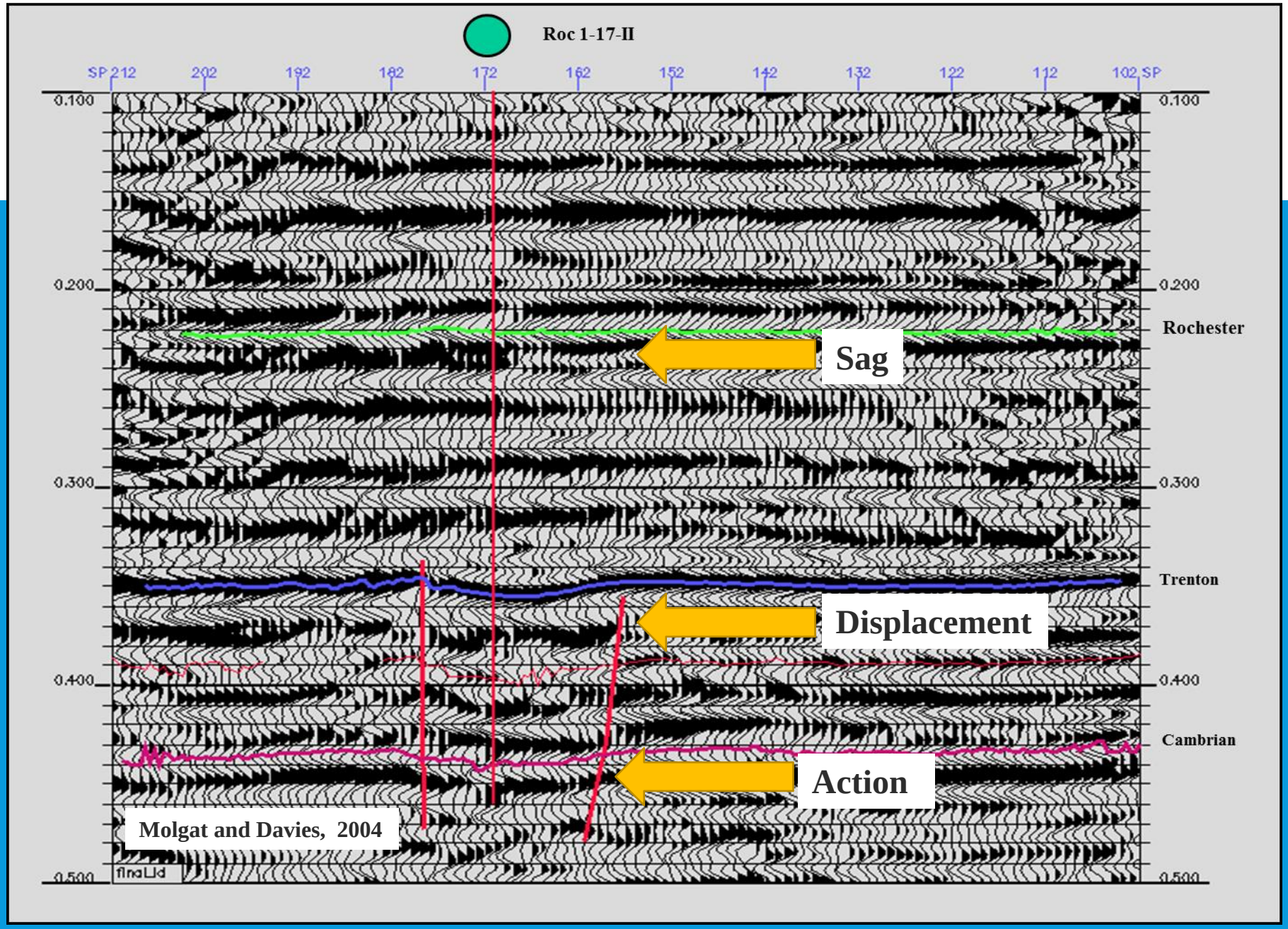

TDs to 1993
1987
COUNTY 42 RD
AIMEE ST
1993
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
1992
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 31 RD
Rochester 5-12-IV
1987
1993
1992
1991
1990
12 + 13 SIDERD
Rochester 7-17-IV EBR Pool
Rochester 1-17-II EBR Pool
BYRNEDALE RD
1987
1993
1991
1992
401 HWY
BELLE RIVER RD
1986
N MIDDLE RD
1987
0
0.25
0.5
1
1.5
2
km


TDs to 1994
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
Rochester 5-12-IV
Rochester 7-17-IV EBR Pool
Rochester 7-17-II EBR Pool
T008222
T008232
T008235
T008237
T008229
T008111
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 31 RD
COUNTY 42 RD
AIMEE ST
12 + 13 SIDERD
BYRNEDALE RD
401 HWY
BELLE RIVER RD
N MIDDLE RD
1993
1992
1991
1990
1994
1987
1986
0
0.25
0.5
1
1.5
2
km

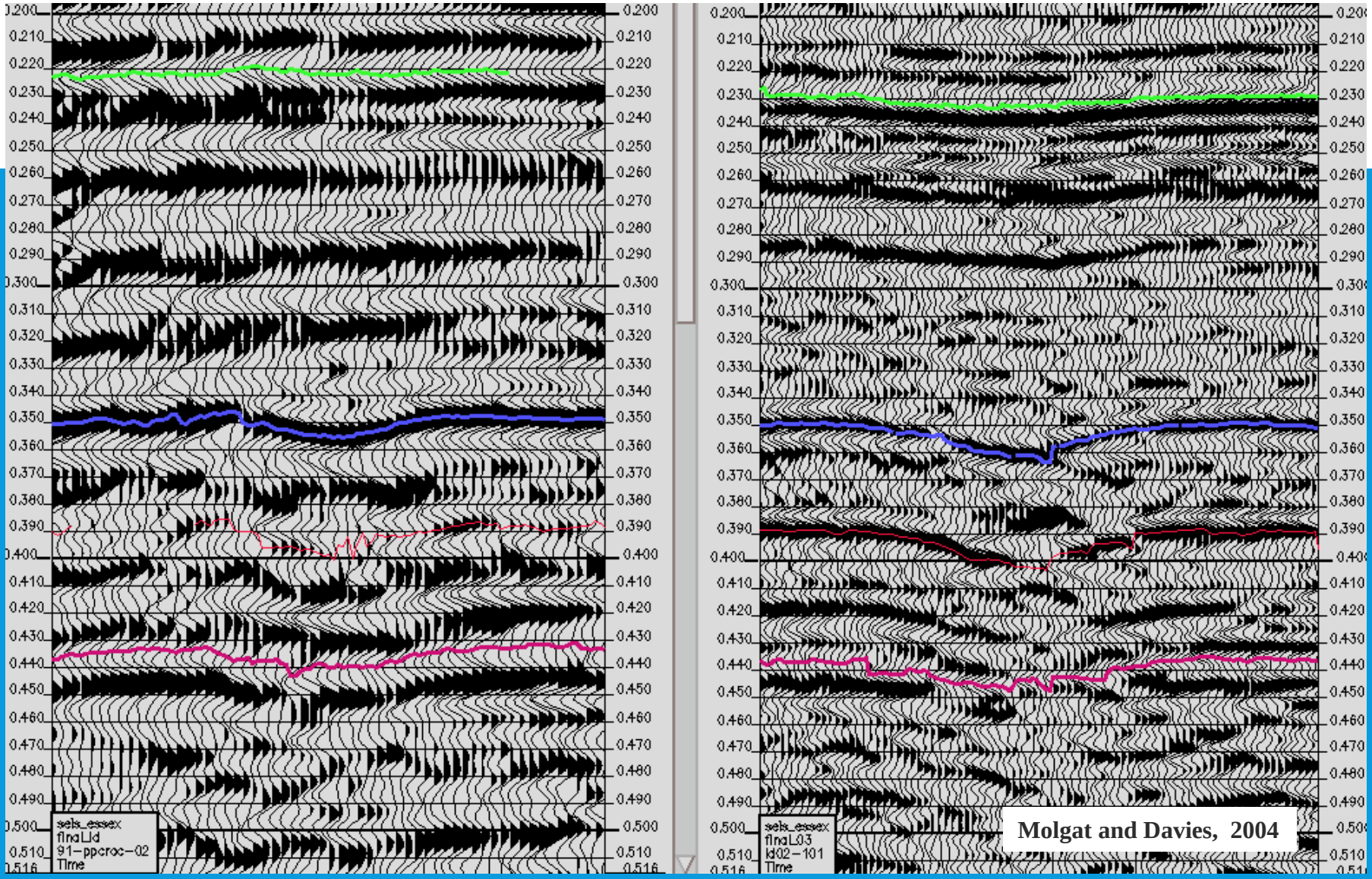

TDs to 1995
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
Rochester 5-12-IV
Rochester 7-17-IV EBR Pool
Rochester 7-17-II EBR Pool
T008222
T008232
T008235
T008237
T008229
T008111
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 31 RD
COUNTY 42 RD
AIMEE ST
12 + 13 SIDERD
BYRNEDALE RD
401 HWY
BELLE RIVER RD
N MIDDLE RD
1993
0
0.25
0.5
1
1.5
2
km


TDs to 2011
Rochester 8-8-I EBR Pool
Rochester 4-8-I EBR Pool
Rochester 5-12-IV
Rochester 7-17-IV EBR Pool
Rochester 7-17-II EBR Pool
T008222
T008232
T008235
T008237
T010443
T012129
T008412
T008229
T010444
T010445
T008111
T008810
CONC 2 RD
CONC 3 RD
CONC 4 RD
COUNTY 31 RD
COUNTY 42 RD
AIMEE ST
12 + 13 SIDERD
BYRNEDALE RD
401 HWY
BELLE RIVER RD
N MIDDLE RD
1995
1993
1992
1987
1994
1991
1990
1986
0
0.25
0.5
1
1.5
2
km

2-D Line: 91-PPC-ROC-02



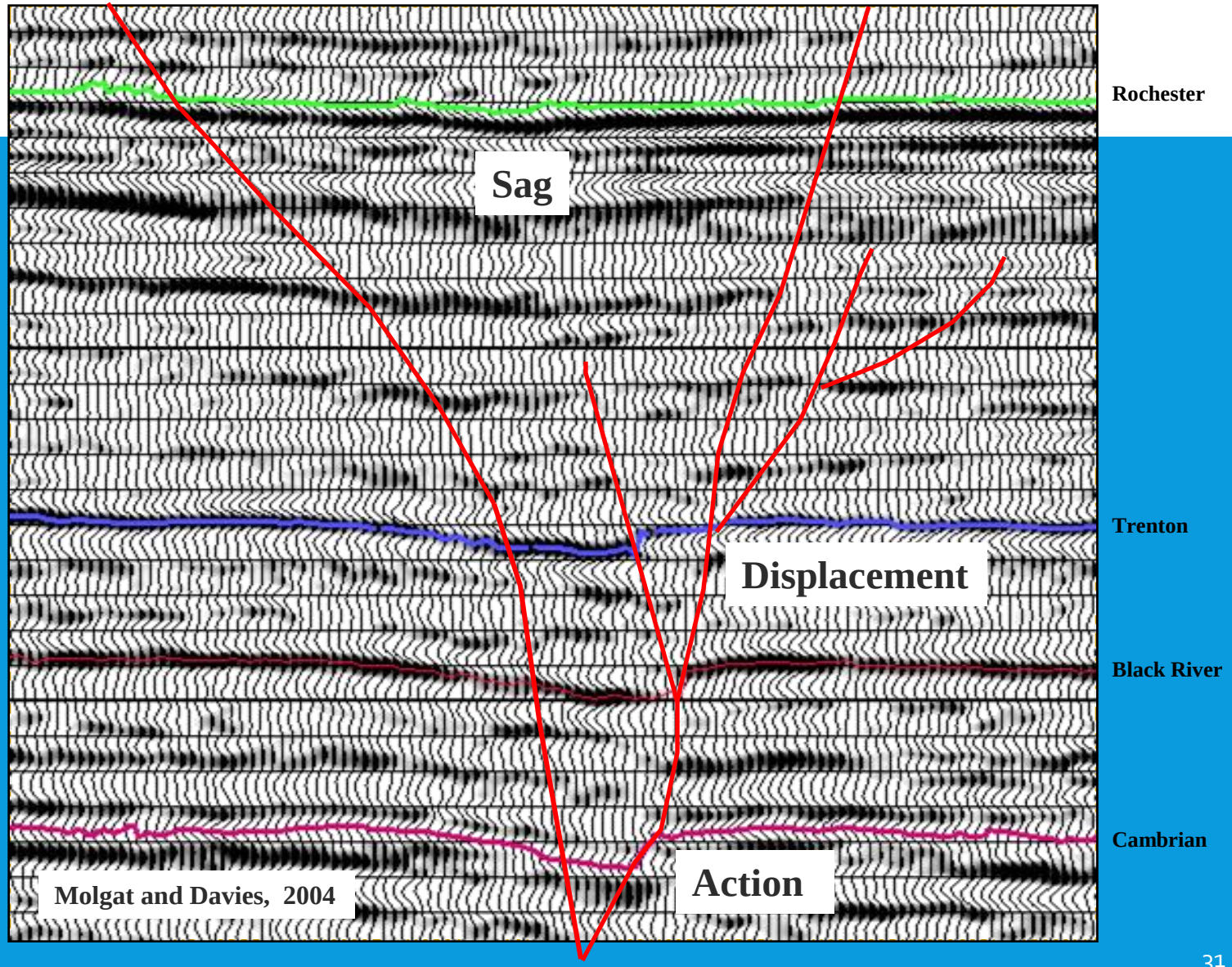
Seismic Data Quality Variations



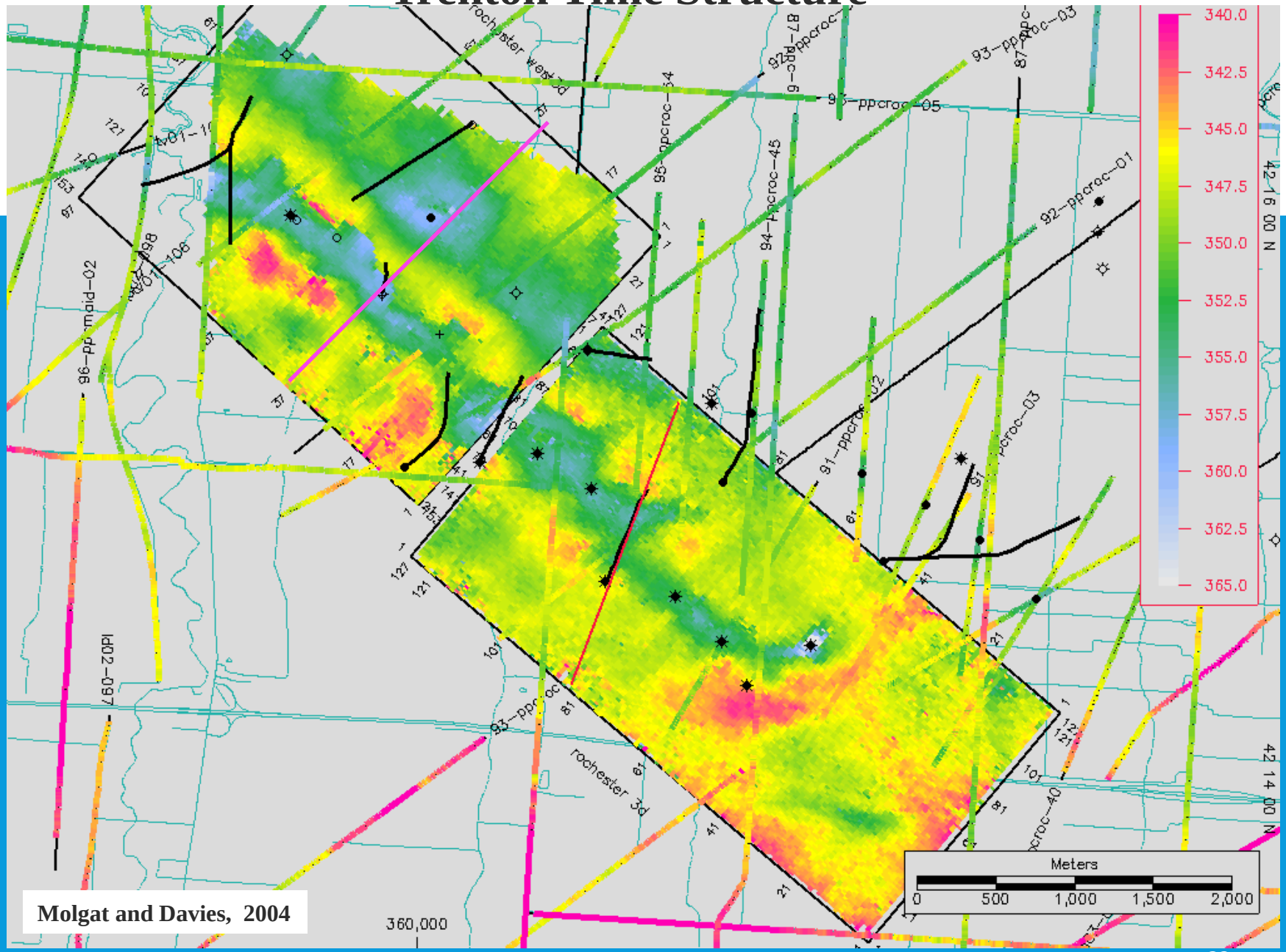
1991 Acquisition

2002 Acquisition

Sample - Trenton Seismic Section

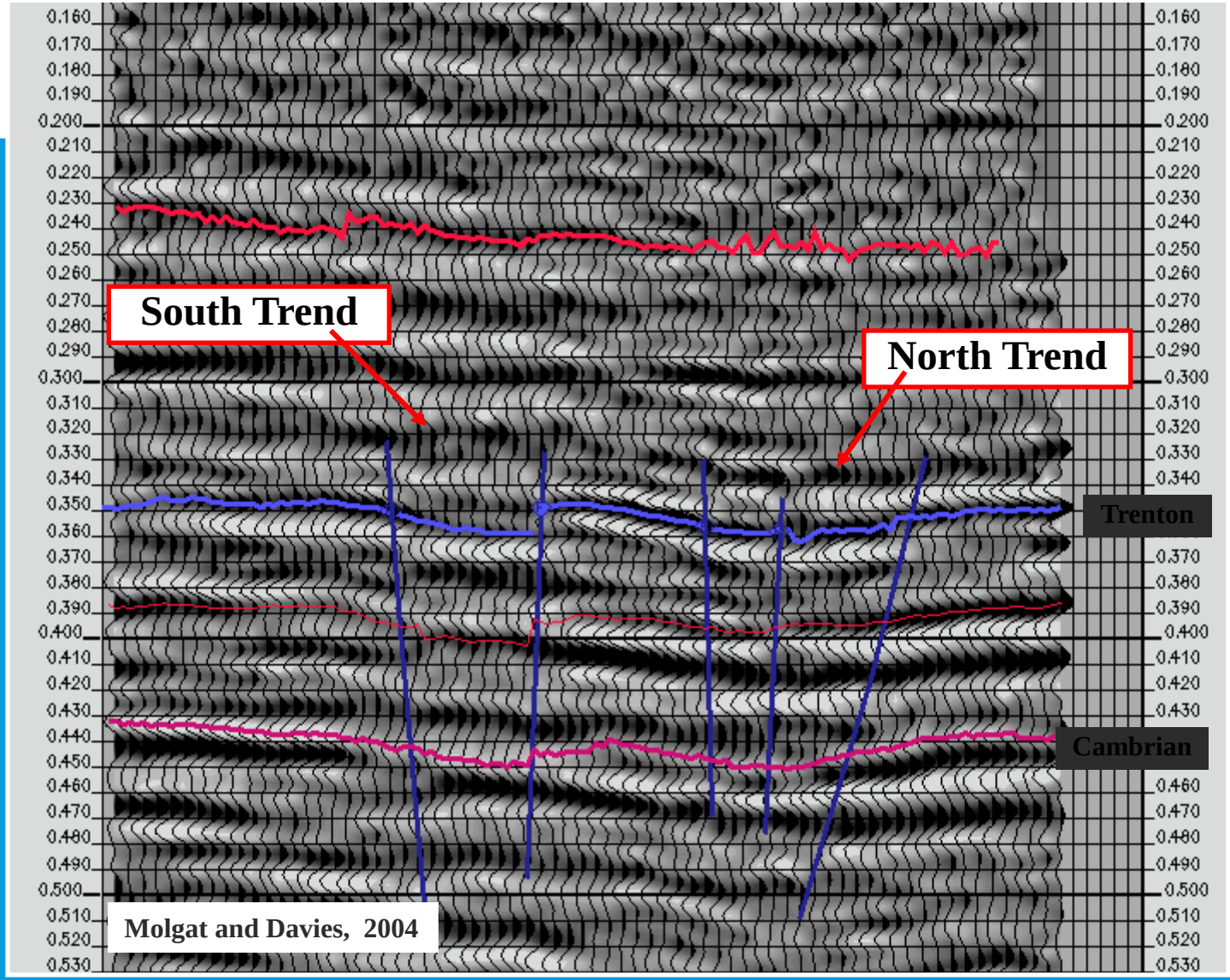


Trenton Time Structure



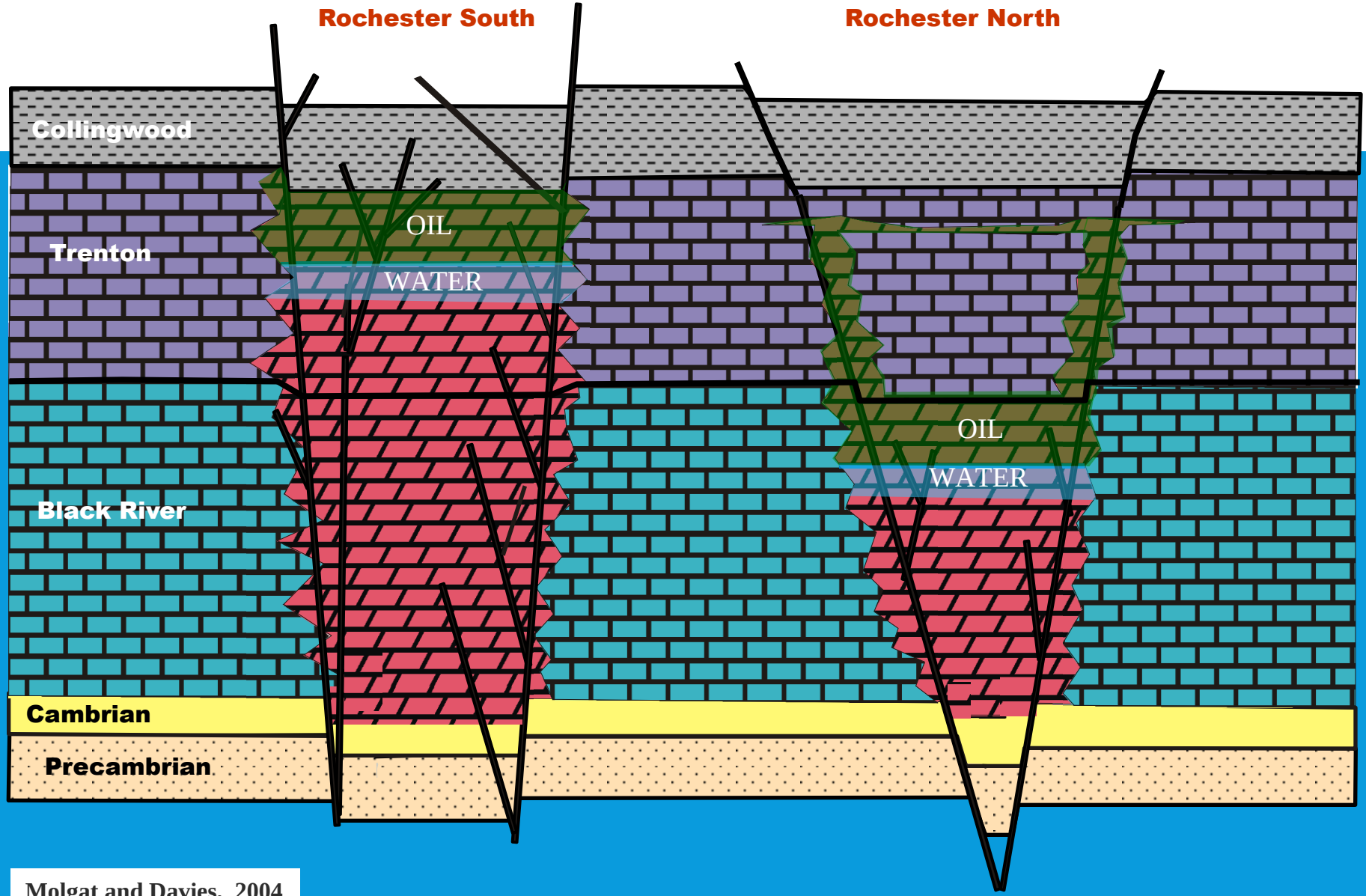
Molgat and Davies, 2004

North and South Trend Comparison



Rochester West 3-D (In-line 37)

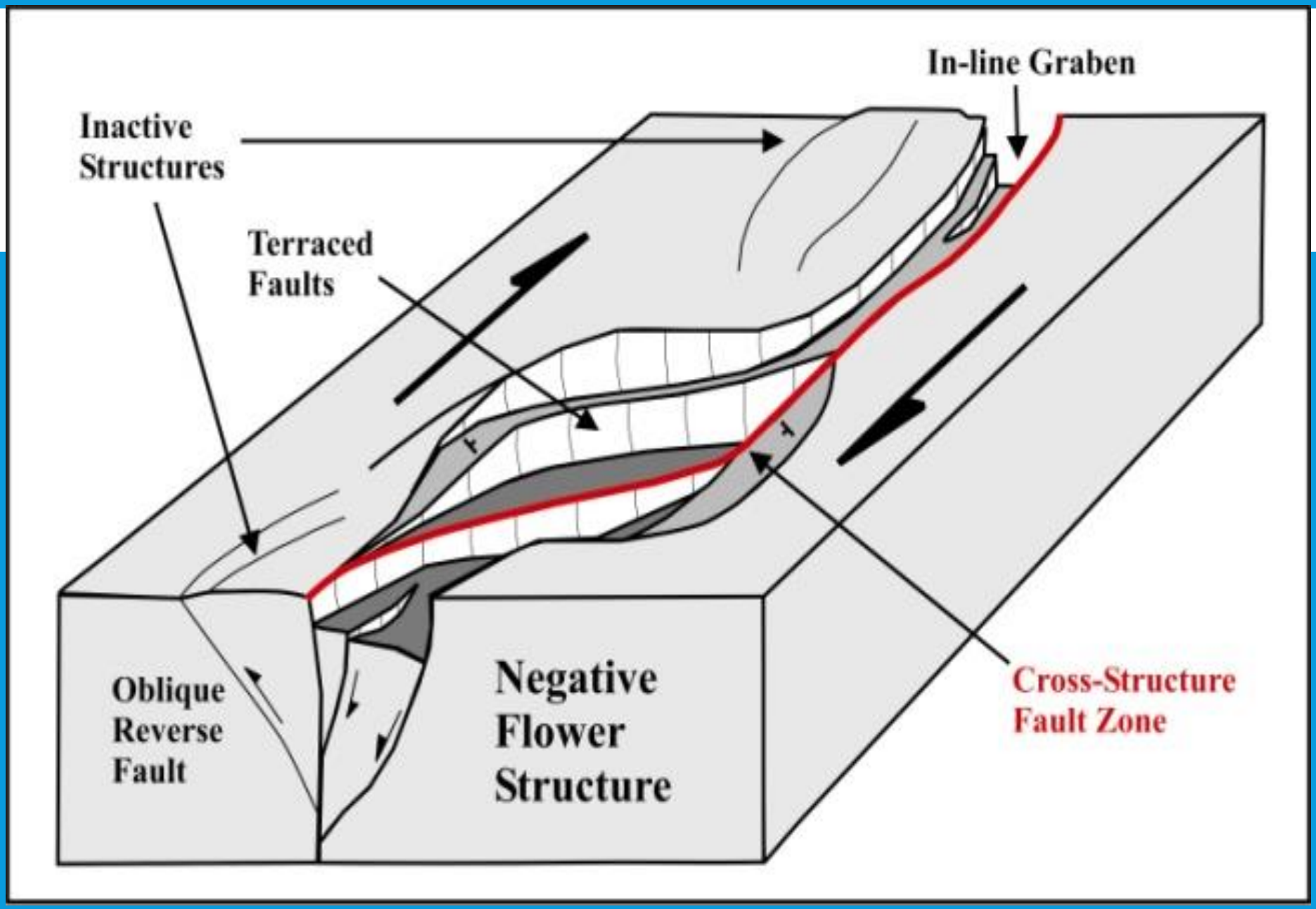
Rochester Model - Talisman 2004



Molgat and Davies, 2004

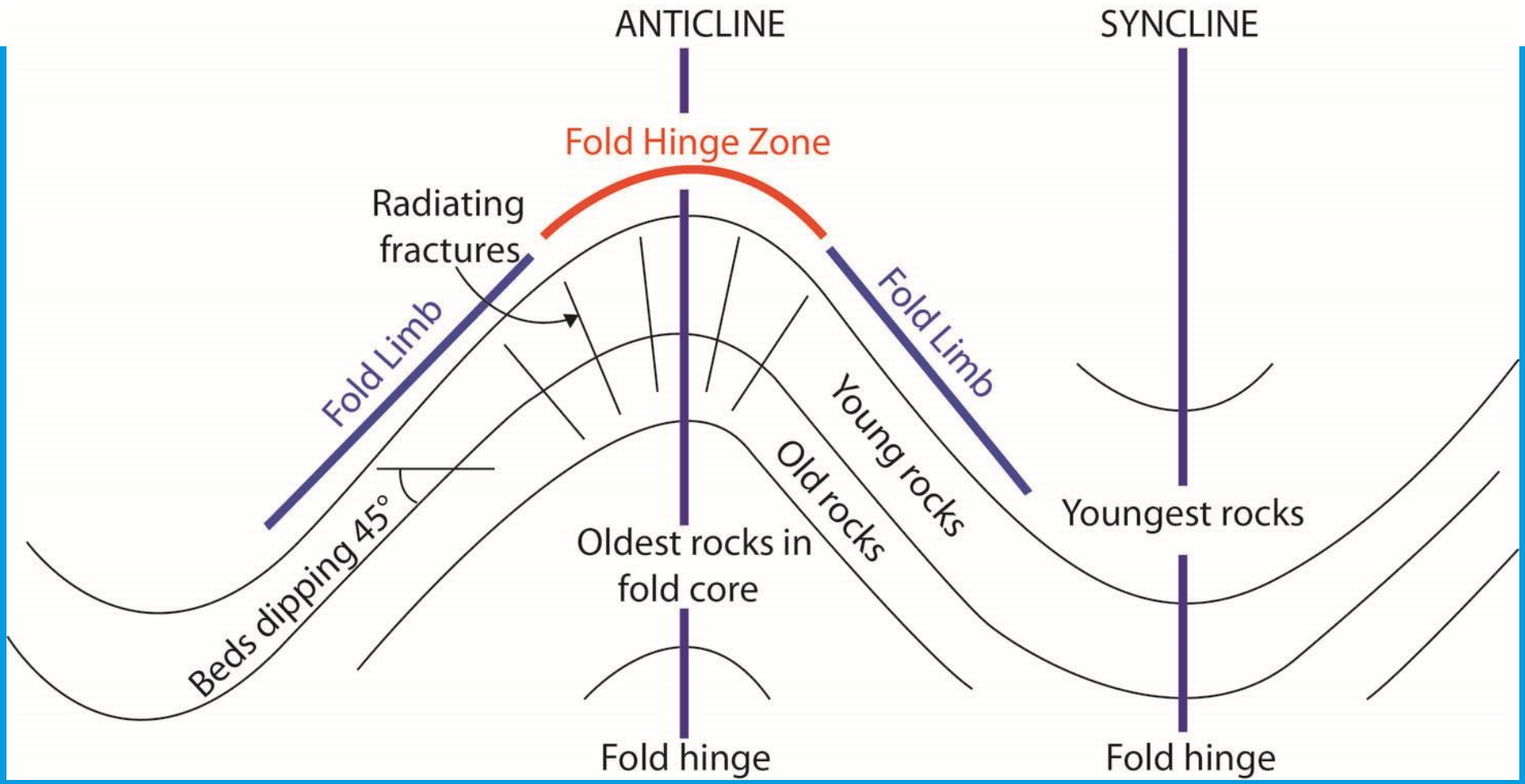
ROCHESTER SOUTH AND NORTH OIL POOLS

- Rochester South Oil Pool was discovered in 1992 by Paragon Petroleum Corporation
- Rochester North Oil Pool was discovered in 1994 by Paragon Petroleum Corporation
- Hydrothermally dolomitized (HTD) Trenton - Black River Group carbonates
- Both pools trend NW-SE, are up to 5 km long and are 300-600 m wide
- Controlled by faults and fractures created by strike-slip movements
- Rochester South and North Oil Pools have 26 producing wells
- Both trends produce oil from the Trenton but the north trend produces oil from the Black River
- Reservoirs: 840 m (2760') and 940 m (3080'); 7800 kPa (1130 psi) and 25^{o}C
- End 2015, cumulative oil production was 2.5 mmbbls
- Estimated to be >92% of the recoverable reserves using a 15% recovery factor
- Porosity: 3-15% (8%) matrix, 18-45% fractures; Permeability: 10–300 md (150 md) in matrix and 2-10 Darcies for fractures
- Oil is sweet, 40^{o} API, with solution gas; water saturation 15 to 40%, irreducible 15 to 20%
- Typical decline rates between 15 and 25% per year

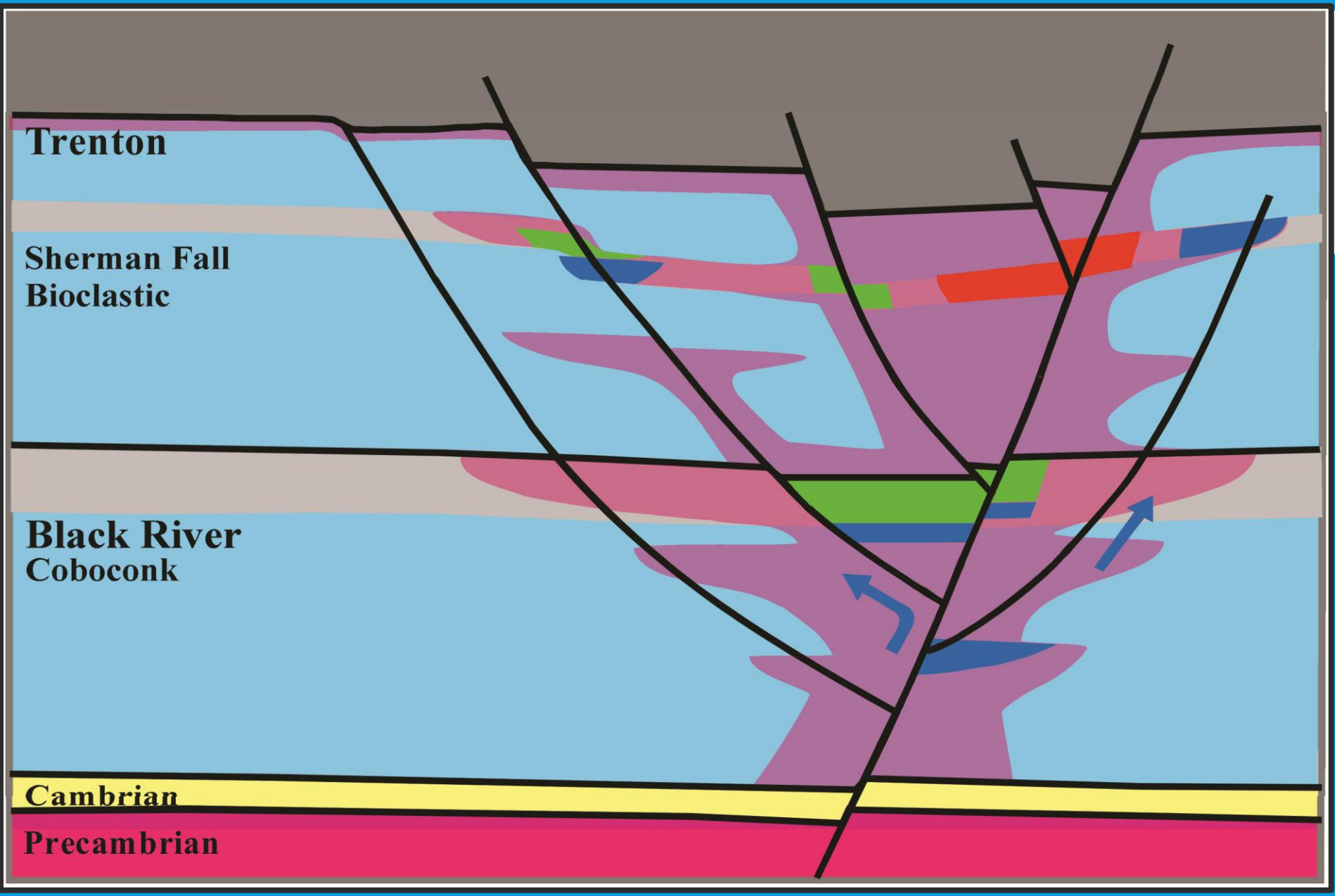


Isometric representation of a pull-apart basin (modified from Dooley and McClay, 1997) showing sag or "graben" structure.

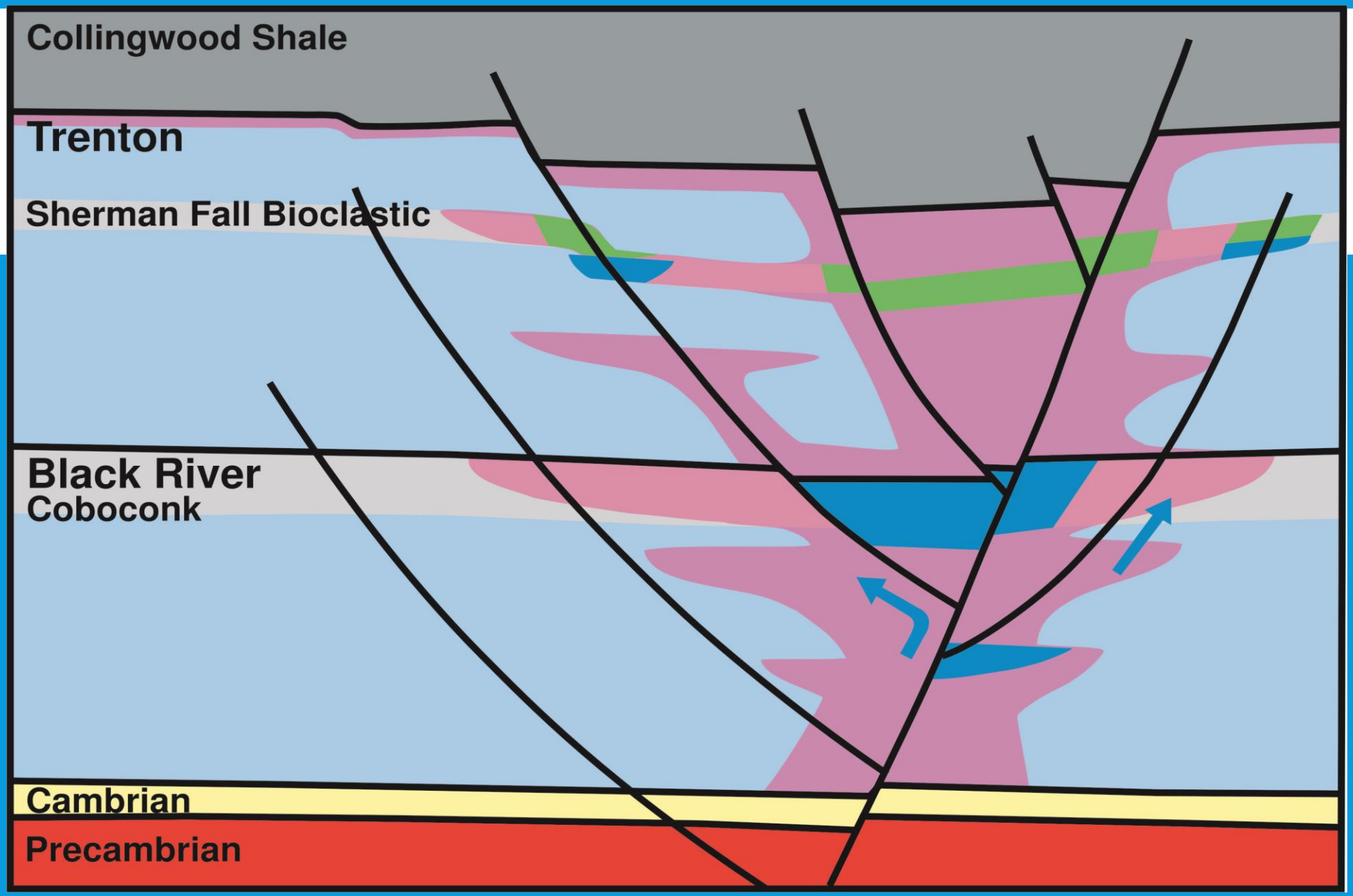
Fracture pattern on an anticlinal form



Fracture pattern and geometry over an Anticlinal form; near vertical on top and high angle on sides



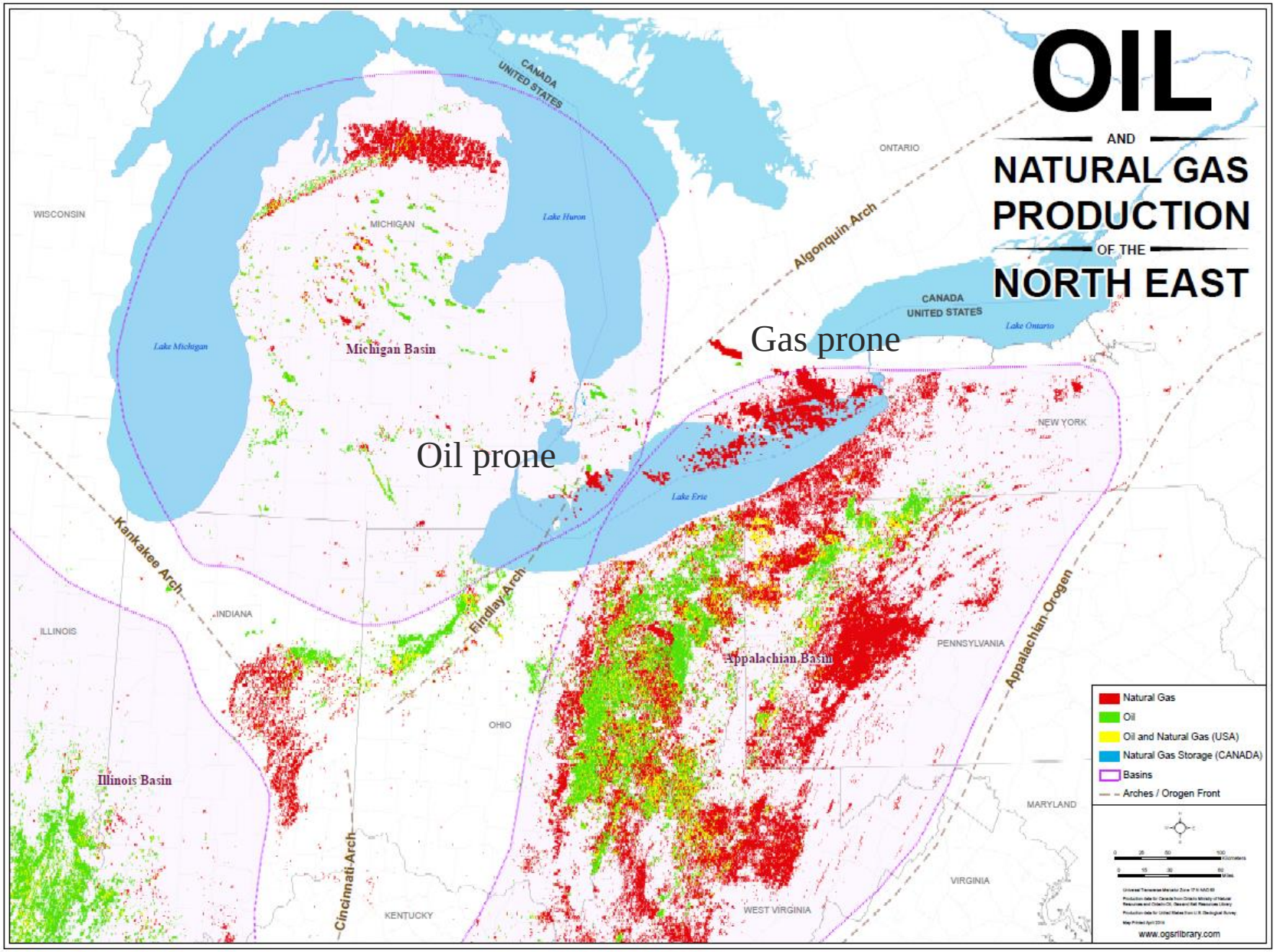
Conceptual model of a Trenton-Black River reservoir at Rochester North and oil and gas pools at Dover. Modified from Colquhoun and Johnston (2004).



Conceptual model of a Trenton-Black River reservoir at Rochester South and other oil pools located in Essex and Kent Counties. Modified from Colquhoun (2012).

EXPLORATION AND DEVELOPMENT HISTORY AND FUTURE POTENTIAL

- Play has been active since the late 1800's, last discovery in 1992 and 1994 at Rochester
- Hydrothermally dolomitized (HTD) Trenton - Black River Group limestones
- Pools trend NW-SE and E-W, up to 15 km long and 300-1000 m wide (Goldsmith-Lakeshore)
- Oil is sweet, 40 – 42° API, with solution gas; typical decline rates between 15 and 25% per year
- Reservoir: 650 m (2130') to 1050 m (3450'); 7800 to 8050 kPa or 1130 to 1170 psi at 25°C;
- Net pay - up to 10 m or 30 feet; Porosity: 3-15% (8%) matrix, 18-45% fractures; Permeability: 10–300 md (150 md) in matrix and 2-10 Darcies for fractures
- Source rock – Middle Ordovician carbonates and Upper Ordovician shale; carbonaceous
- Seal – upper cap dolomite and overlaying shale; lateral seal is impermeable limestones
- Play occupies approximately 120,000 km^2
- Potential oil recoverable: 40 mmbbls; 23 mmbbls recoverable; 17 mmbbls remaining (Golder 2005)
- Potential gas recoverable: 281 bcf; 41 bcf recoverable; 240 bcf remaining (Golder 2005)
- Oil production in Essex and Kent Counties; oil potential in northwest Lambton County where Cambrian sandstones are thick; gas production from fractured limestones in Lambton County over Arch
- Gas prone from Elgin County east to Welland County and north over the Algonquin Arch
- Historical success rates: 80's and 90's -- 67% for exploration wells and 80% for development wells
- Seismically driven play, 2-D to locate test drill target, 3-D to explore and develop pool(s)



Map showing Ordovician oil and gas pools and future exploration potential

THANK YOU FOR LISTENING

ANY QUESTIONS?