



# **Core Workshop**

**Middle Ordovician and  
Cambrian-aged sediments,  
Southwestern Ontario**

**Ian Colquhoun**

2024-06-06



Slide 1: Middle Ordovician and Cambrian sediments of SW Ontario.

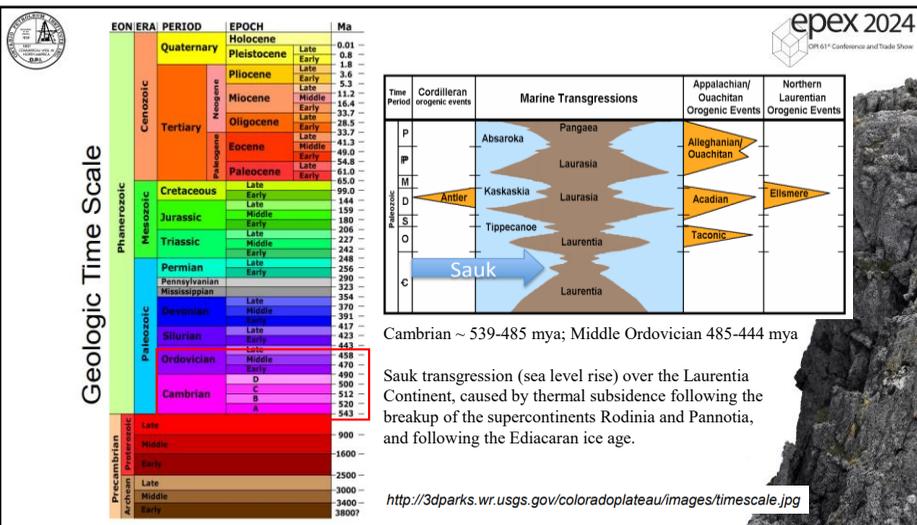


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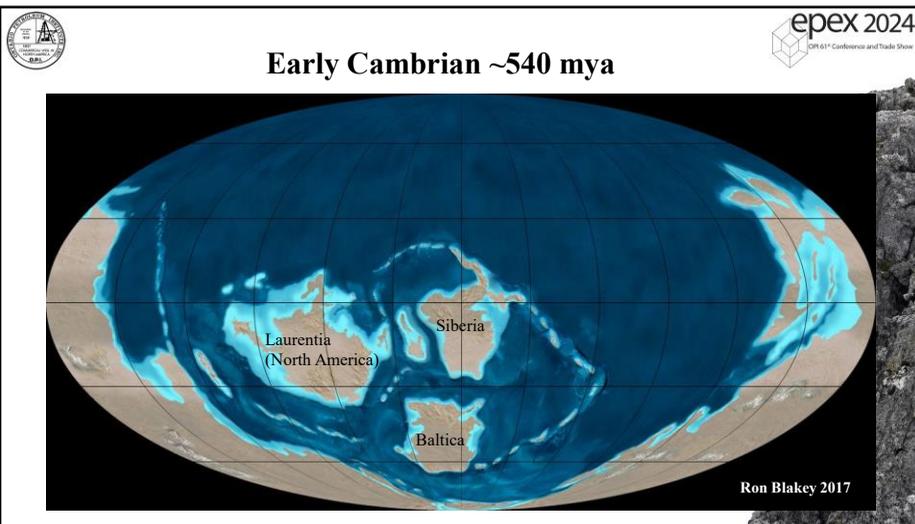
Ian Colquhoun, June 6, 2024  
Prepared for the Ontario Oil, Gas, & Salt Resources Corporation  
with support from Geofirma Engineering Ltd. and Baker Hughes



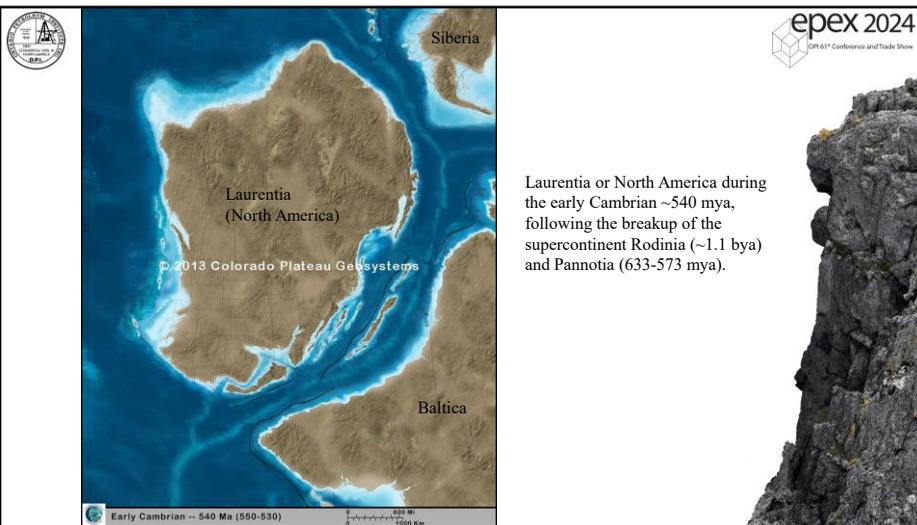


Slide 2: With respect to North America, the Cambrian began ~539 mya and continued until 485 mya, which was followed by the Middle Ordovician that continued until 444 mya. The Sauk Transgression, named after a significant sea level rise over the continental land mass of Laurentia (North America), led to the deposition of sandstones, sandy limestones, and limestones of Cambrian and Middle Ordovician ages. This was followed by the deposition of the Shadow Lake Formation and the limestones of the Trenton and Black River Groups of Middle Ordovician age. Smaller transgressive and regressive cycles occurred during the Sauk transgression, and they are captured in my lithological descriptions of the Cambrian-aged rocks. This transgression was caused by thermal subsidence that followed the breakup of the supercontinents of Rodinia and Pannotia, and the Ediacaran ice age.

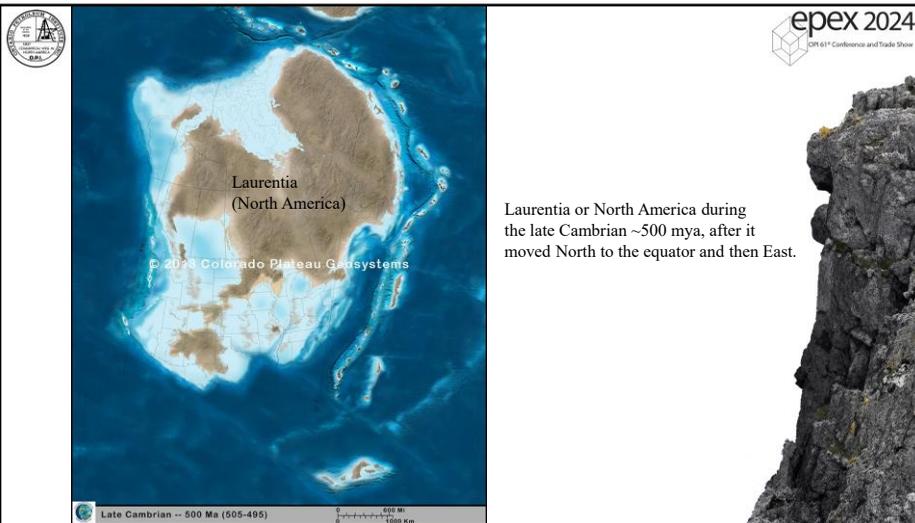
Slide 3: Here we see the position of the continents of Laurentia (North America), Siberia and Baltica during the Early Cambrian, ~540 mya. The continents were located south of the equator and began to move away from each other following the breakup of the supercontinents.



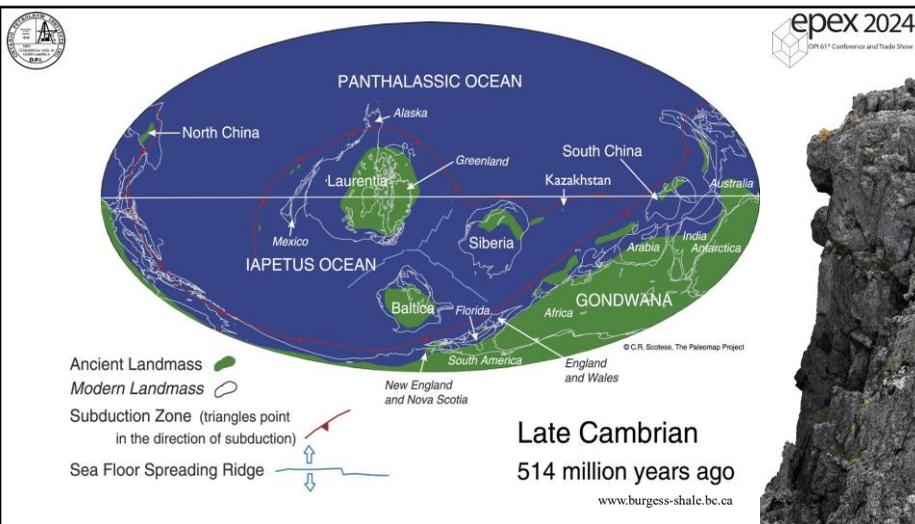
Slide 4: A close-up of Laurentia during the Early Cambrian, ~540 mya. Note the separation of Laurentia from the continents of Baltica and Siberia that began to drift north towards the equator.



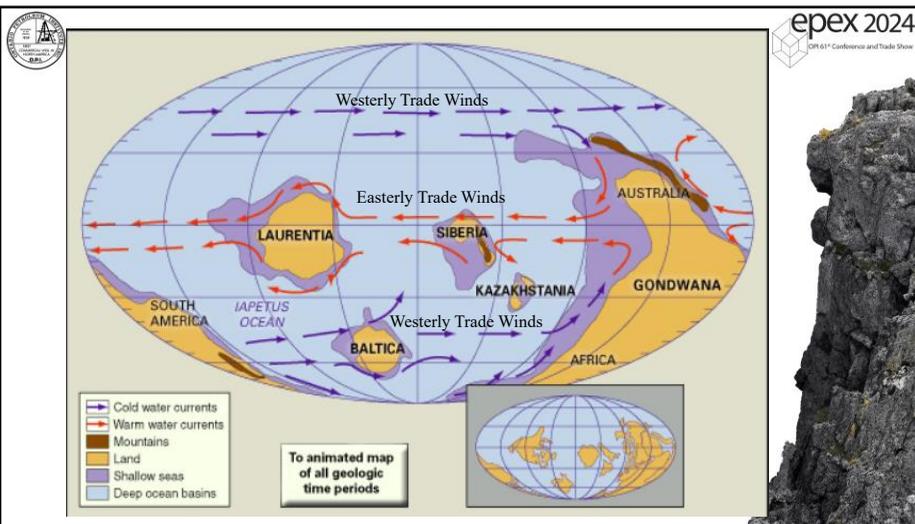
Slide 5: A close-up of Laurentia during the Late Cambrian, ~500 mya, following its movement North to the equator and then its movement to the East. Note the inundation of the seas along the continental margins.



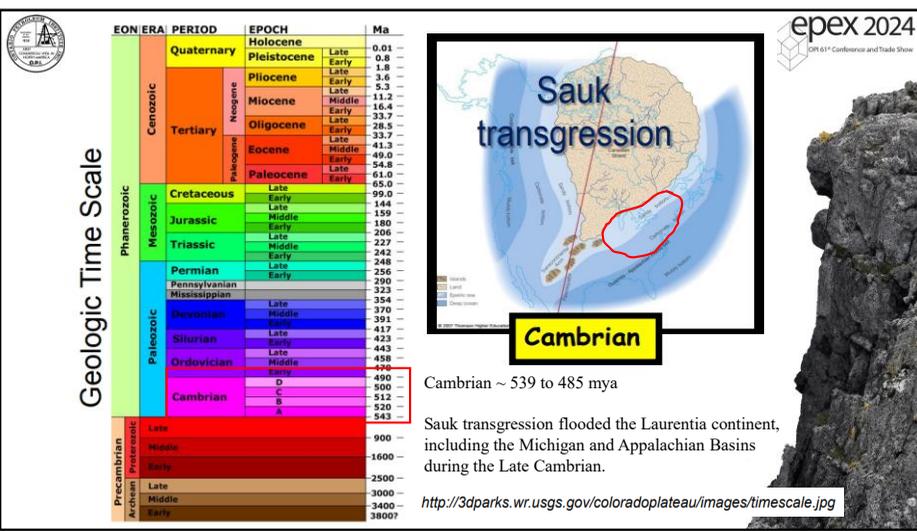
Slide 6: A snapshot of the continents at ~514 mya, Laurentia is at the equator and moving East along with the continents of Baltica and Siberia. Note their position within the Panthalassic and Iapetus oceans.



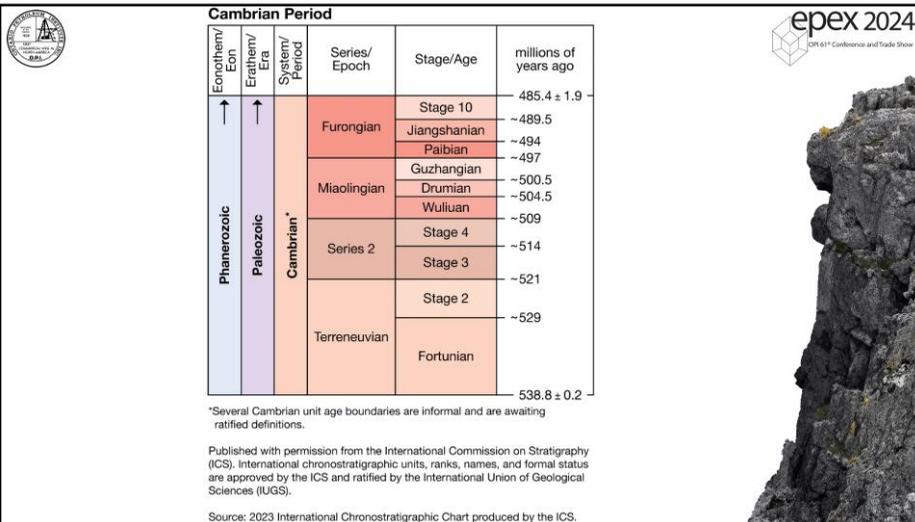
Slide 7: The continent of Laurentia was inundated by easterly trade winds that formed along the equator which dictated the track of storms generated from the extensive Panthalassic and Iapetus Oceans.



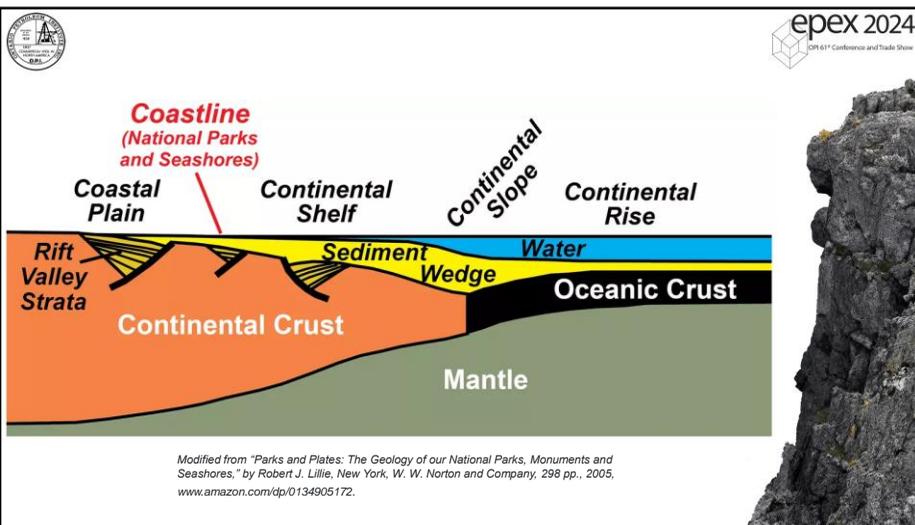
Slide 8: The Sauk Transgression was responsible for the flooding of coastal Laurentia and the deposition of Cambrian-aged sediments within the Michigan and Appalachian Basins, this area is highlighted in the red circle.



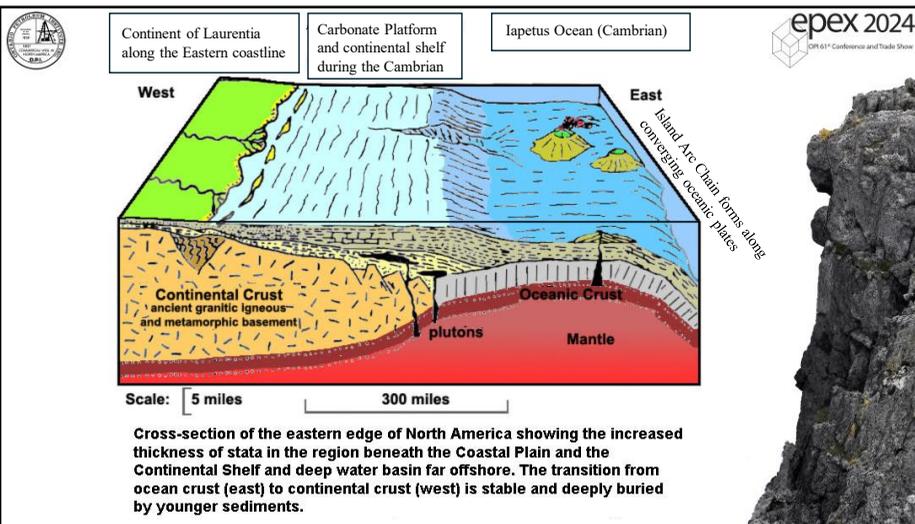
Slide 9: The Cambrian Period is being studied in detail today and these studies have proposed age boundaries for several stratigraphic units. These units are awaiting formal definitions that will need to be ratified by the International Commission on Stratigraphy (ICS).



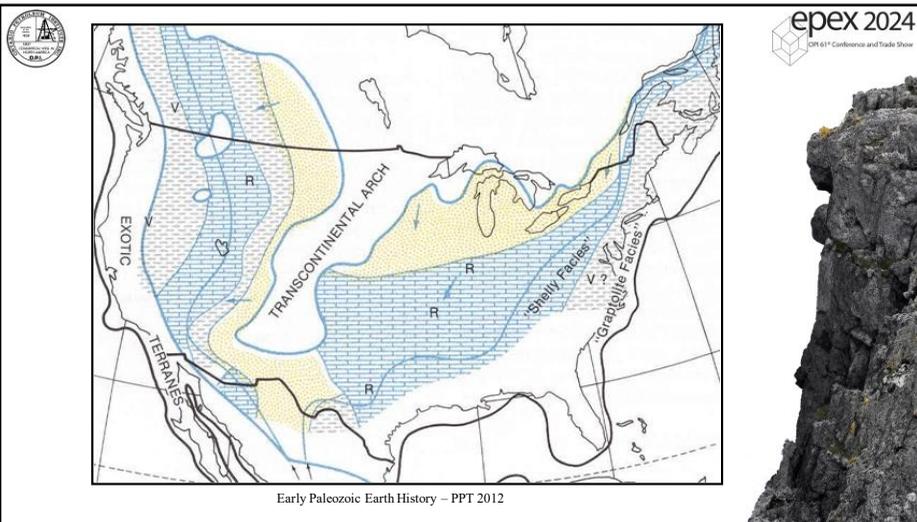
Slide 10: A cartoon of the geology for a continental shelf, which was the product of a passive continental margin during the Cambrian. A continental shelf was present on both the Eastern and Western coastlines of the Laurentian continent.



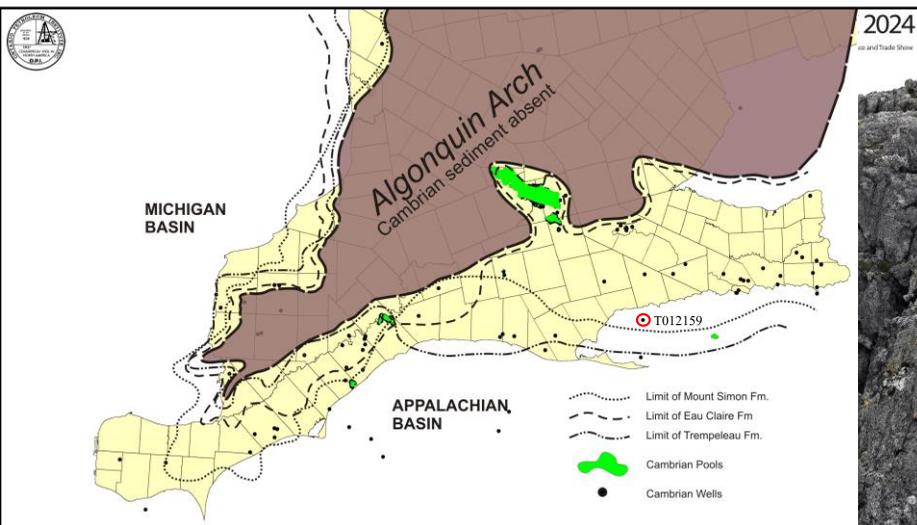
Slide 11: A cartoon of the passive continental margin during the Cambrian along Eastern Laurentia showing the broad carbonate platform that extends outward towards the deeper parts of the carbonate shelf and the Island Arc chain. The Island Arch chain was created by the subduction of an oceanic plate underneath another oceanic plate along a convergent plate boundary. The collision of Laurentia with this Island Arch chain marks the earliest formation of the Appalachian Mountains during the Taconic Orogeny, but that is a story for another time.



Slide 12: North America paleogeography during Cambrian time, the transcontinental arch stretches from Arizona northeast into Canada and divides the Laurentian continent. Depositional facies along the Eastern Laurentia continent includes sandstones near the paleo-shoreline, a broad area of limestones, and shales representing deeper water sediments farther offshore along the carbonate platform.



Slide 13: Today, the Cambrian sediments pinch out against the Algonquin Arch. This map shows the depositional limits for the Eau Claire, Mount Simon and Trempleau formations generated from data within OPDS. Our focus is on the geological description of the Middle Ordovician and Cambrian-aged sediments in core 1130 of well T012159, which was drilled by Dundee Energy in 2012.



Slide 14: Slide is annotated.



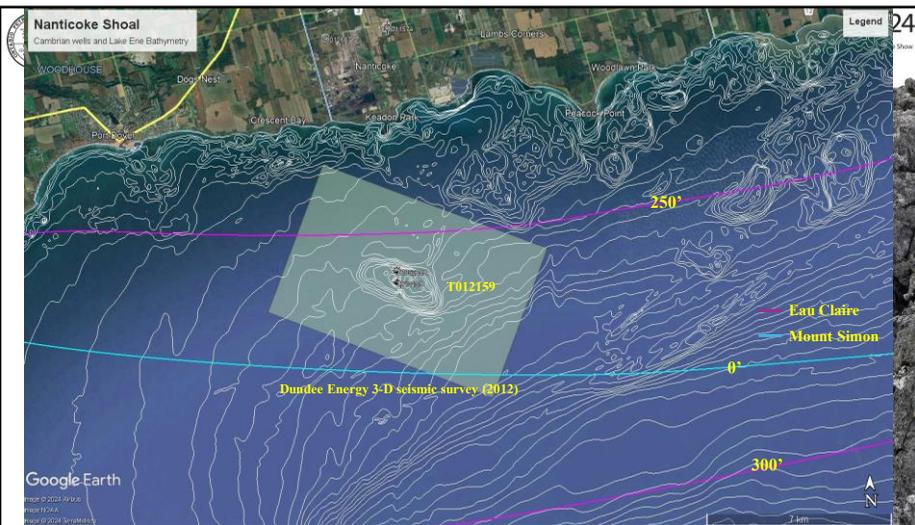
**Dundee East, Lake Erie 45-E-4C  
T012159 - STR-ABD  
Gas Shows in Shadow Lake and Eau Claire**

**Dundee Corporation  
D&C in Sept 2012 ; P&A in July 2018**

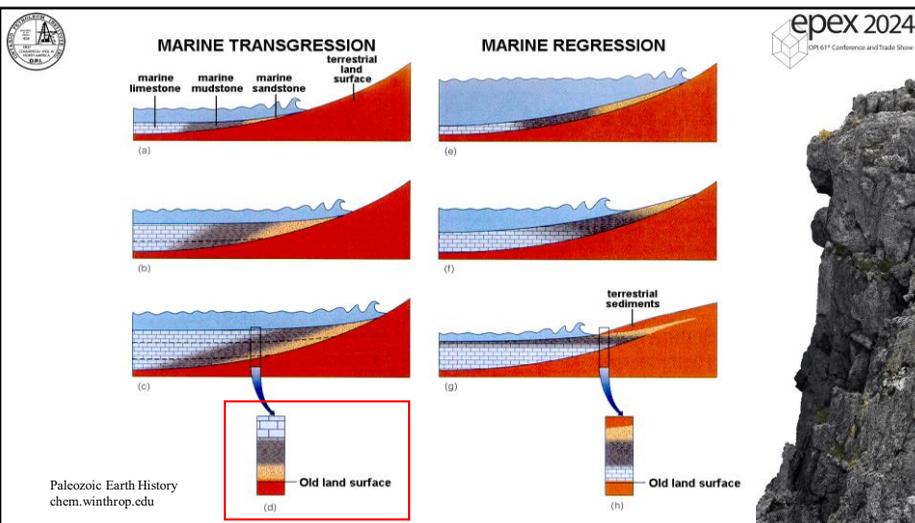
**Core #1130 – 1000 m to 1107.6 mKB**



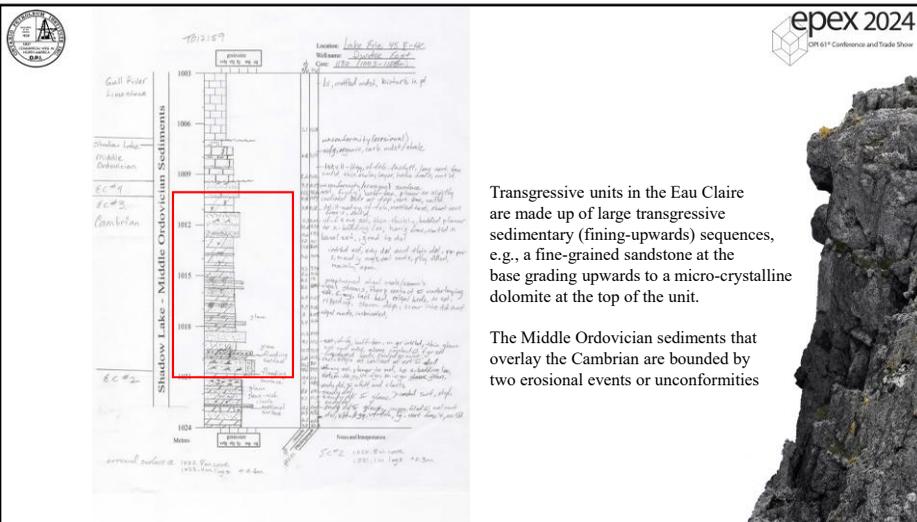
Slide 15: Dundee Energy shot a large 3-D seismic survey in 2012 over the Nanticoke Shoal, a well-known structural feature on the lakebed of Lake Erie, offshore Nanticoke. The shoal was identified as a structural high and a potential horst block structure reflected in the Paleozoic rocks below. Dundee targeted this feature looking for a gas storage container offshore Lake Erie directly south of the town of Nanticoke where Imperial Oil and Stelco have their industrial operations.



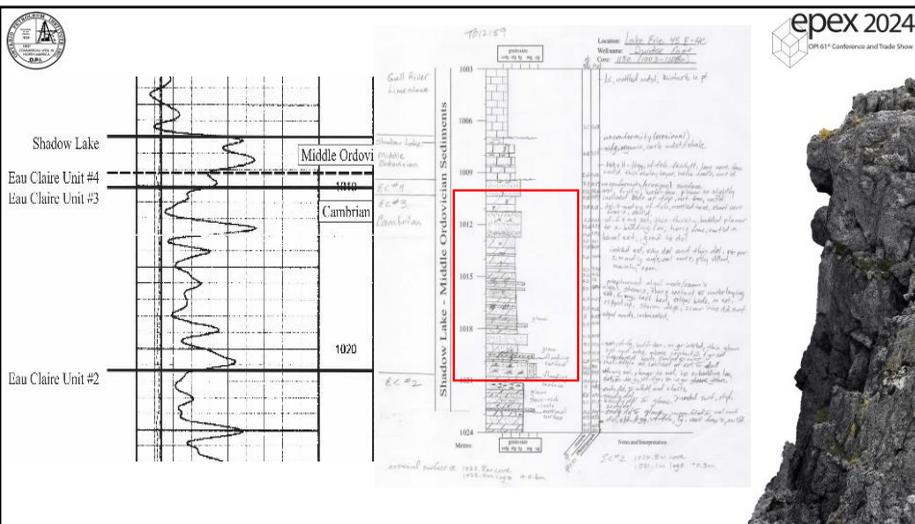
Slide 16: For this core workshop, I have described the geology of the Middle Ordovician and Cambrian sediments in core 1130 based upon a transgressive sequence or cycles of sedimentation, the image on the left-hand side of this slide. A transgressive sequence is depicted as a coarser-grained sandstone, overlying an old land surface, that grades upwards into a very fine-grained limestone at the top, this is referred to as a fining-upward sequence.

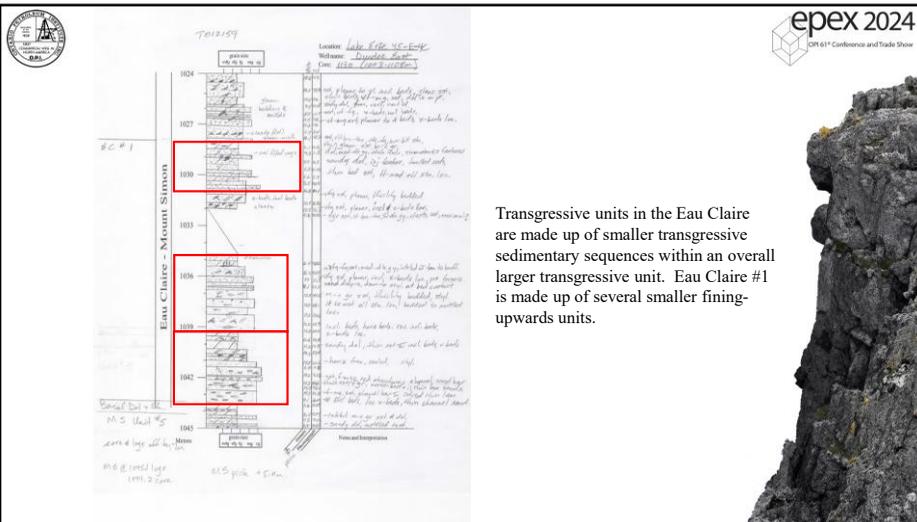


I identified several units in the Eau Claire and Mount Simon formations in core 1130 using this simple geological relationship and I was able to correlate them over large distances, laterally to observe facies changes, and from onshore to offshore positions to calculate their dip into the Appalachian Basin. I was able to do this only after examining Cambrian sediments from many cores across SW Ontario, describing these rocks in detail on lithological logs, and correlating their GR and sometimes the GR-NEU log signatures.



Slide 18: Fining upwards sequence for Eau Claire #3 on the lithology and the geophysical logs. Note the high gamma sandstone at the bottom that grades upwards to low gamma and fine-grained dolomite at the top of the unit.

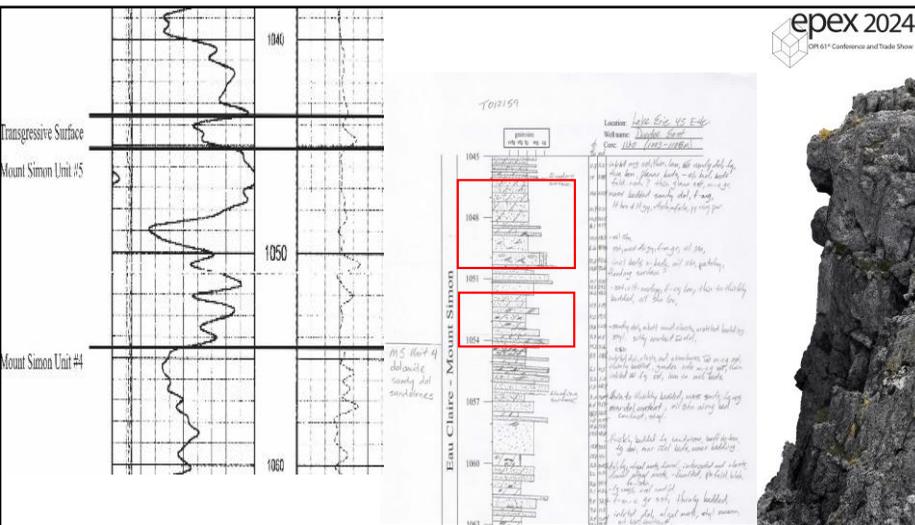




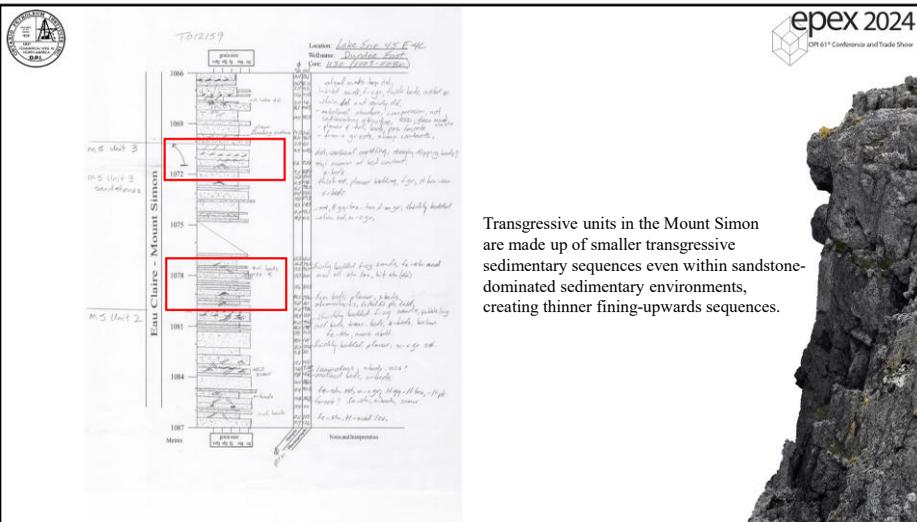
Transgressive units in the Eau Claire are made up of smaller transgressive sedimentary sequences within an overall larger transgressive unit. Eau Claire #1 is made up of several smaller fining-upwards units.



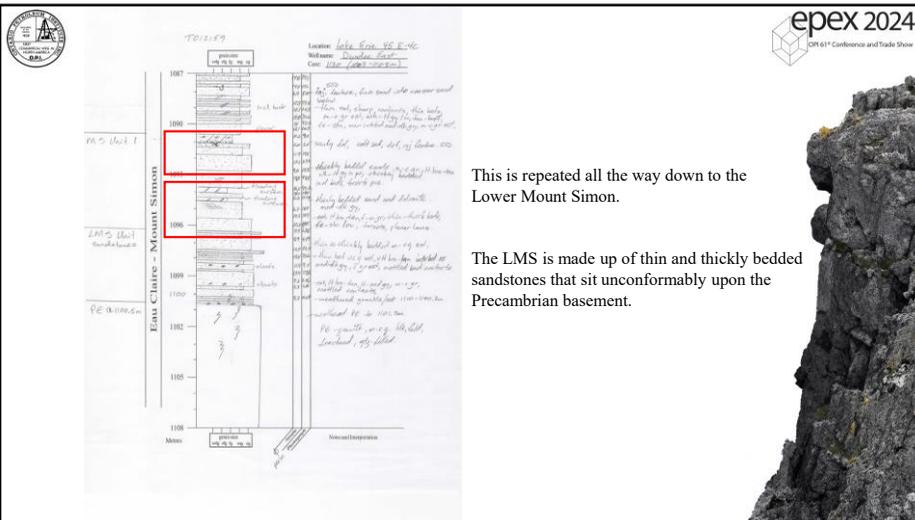
Slide 21: Fining upwards sequence for Mount Simon #5. High gamma sandstone at the base that grades upwards to low gamma and finer-grained sandy dolomite at the top of the unit.

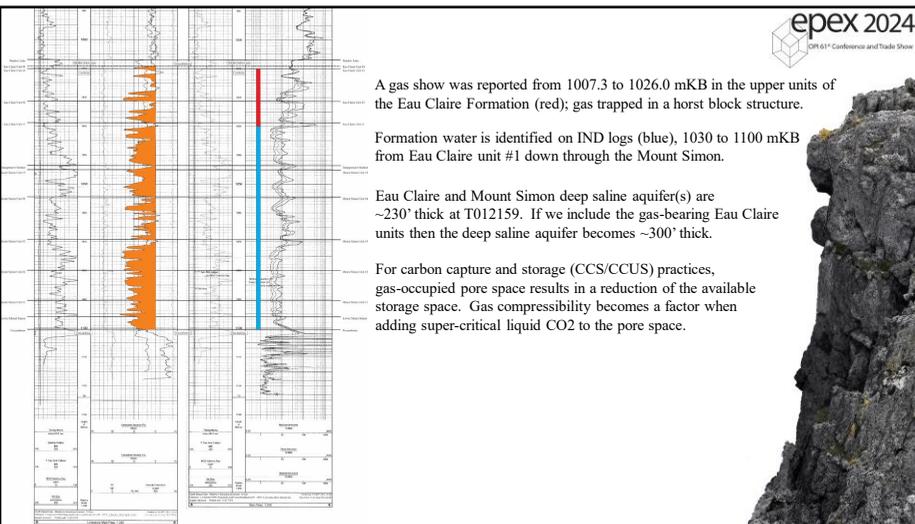


Slide 22: Slide is annotated.

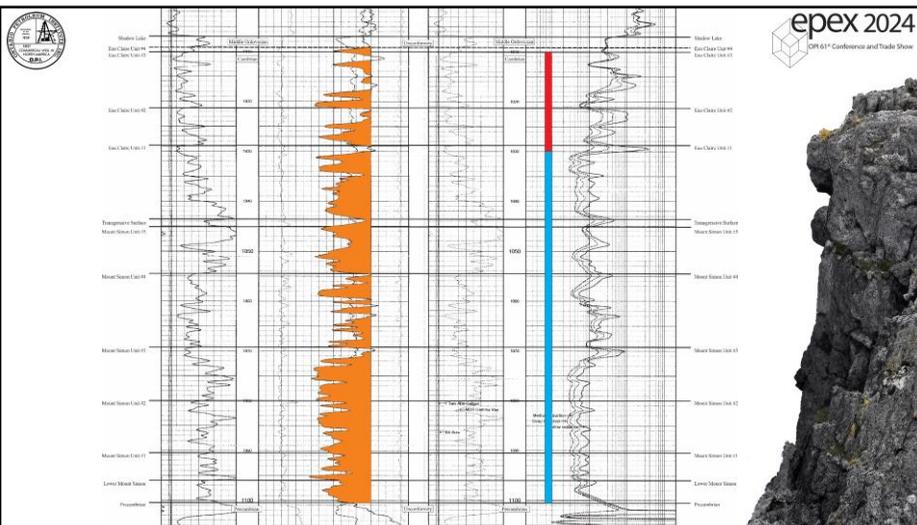


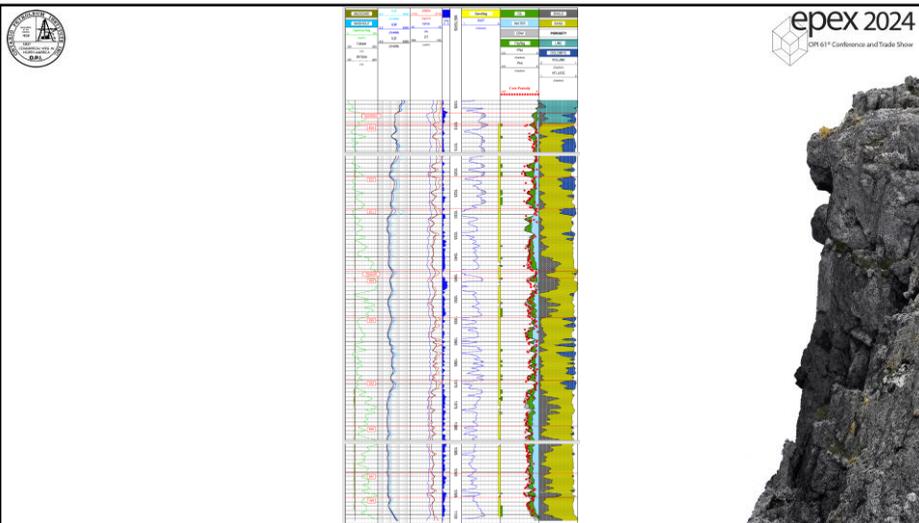
Slide 23: Slide is annotated.





Slide 25: The Middle Ordovician and Cambrian units are identified on the geophysical logs of T012159 along with the gas- and water-bearing portions of the well.





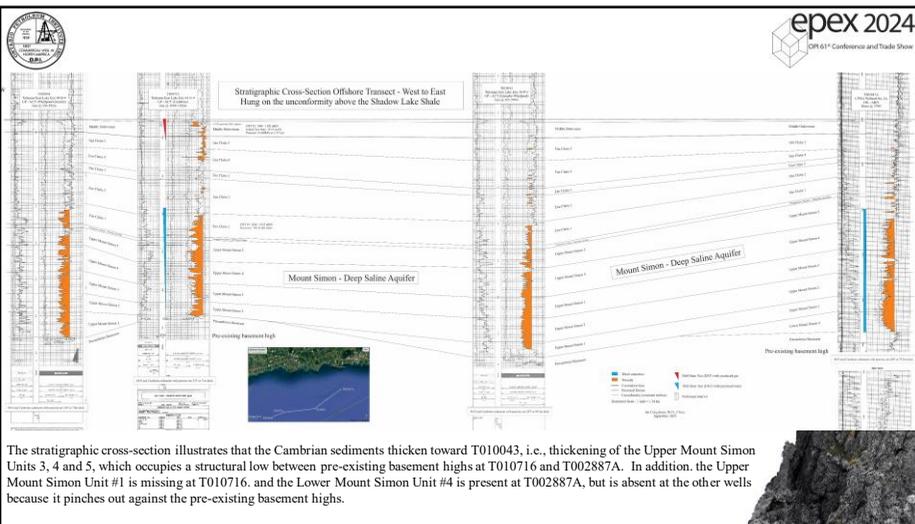
Slide 26: Petrophysical analysis of the geophysical logs from T012159. Baker Hughes ran a stochastic petrophysical log analysis using the data from the porosity and resistivity logs. There are a couple high-level items to mention, the effective porosity and movable hydrocarbons (dark green) are much higher from the Middle Ordovician sediments down to the top of Eau Claire #1. Below EC#1 the movable water fraction (light blue) increases dramatically to the bottom of the hole. This correlates very well with the reported shows of gas and water during drilling of the well. The pay flags mark the areas that will likely give up fluids within the rock based upon the reservoir parameters that we input into the model.



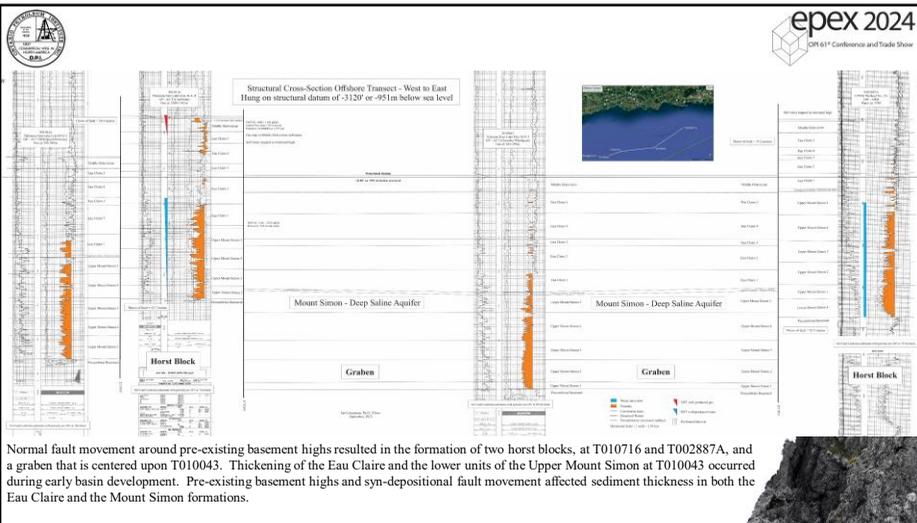
Slide 28: This is a four well transect located offshore Lake Erie used to create stratigraphic and structural cross-sections to map the Middle Ordovician and Cambrian sediments. The log picks for the sedimentary units are based upon the core descriptions and log signatures from core 1130, as identified by this author. I propose that we accept the sedimentary units for the Eau Claire and Mount Simon formations for the purpose of our discussion today. If there are future changes to the nomenclature, then I will update this presentation.



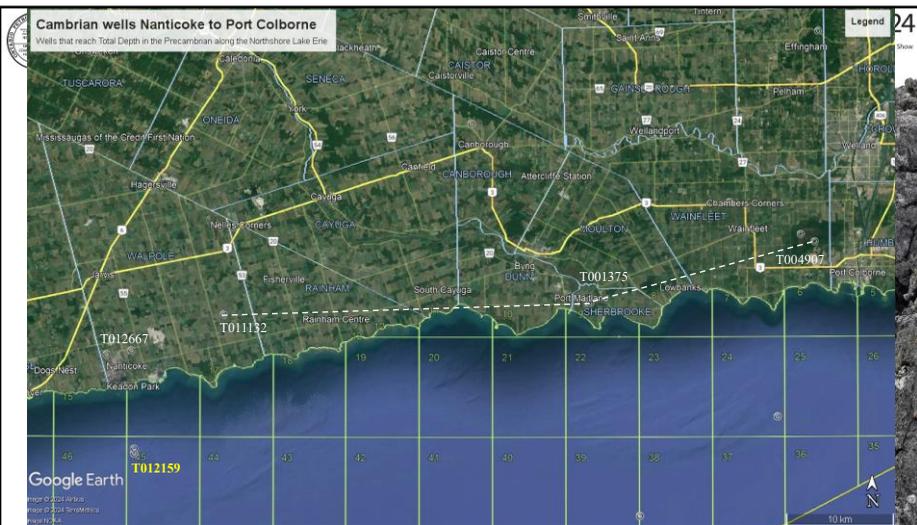
Slide 29: Slide is annotated.



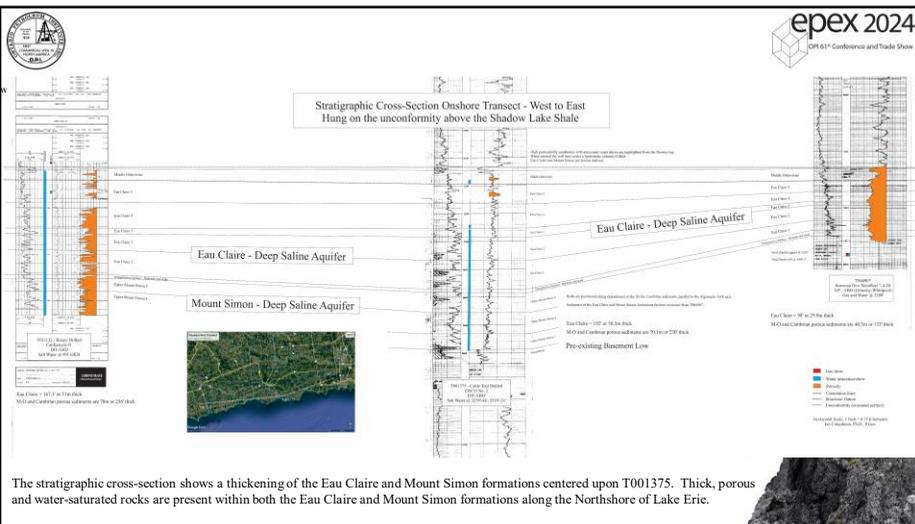
Slide 30: Slide is annotated.



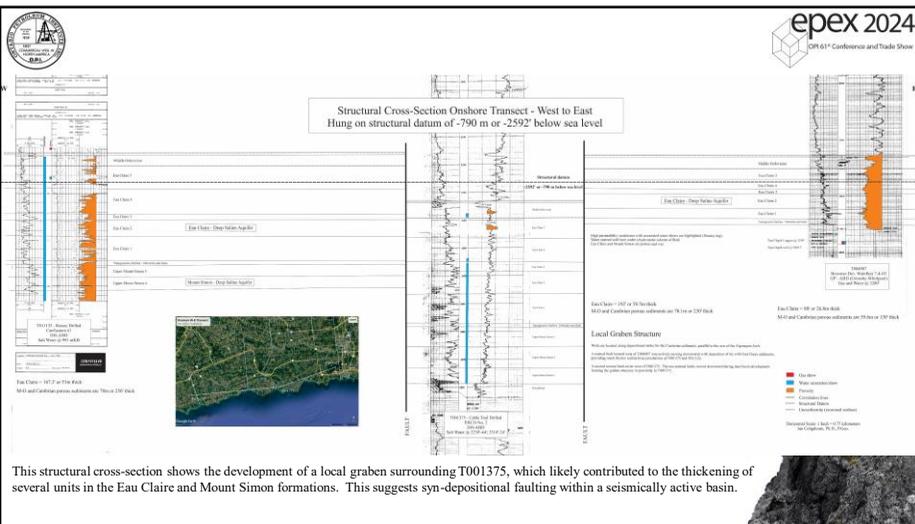
Slide 31: A three well transect along the Northshore of Lake Erie used to correlate the sedimentary units but deposited in shallower sedimentary environments.



Slide 32: Slide is annotated.



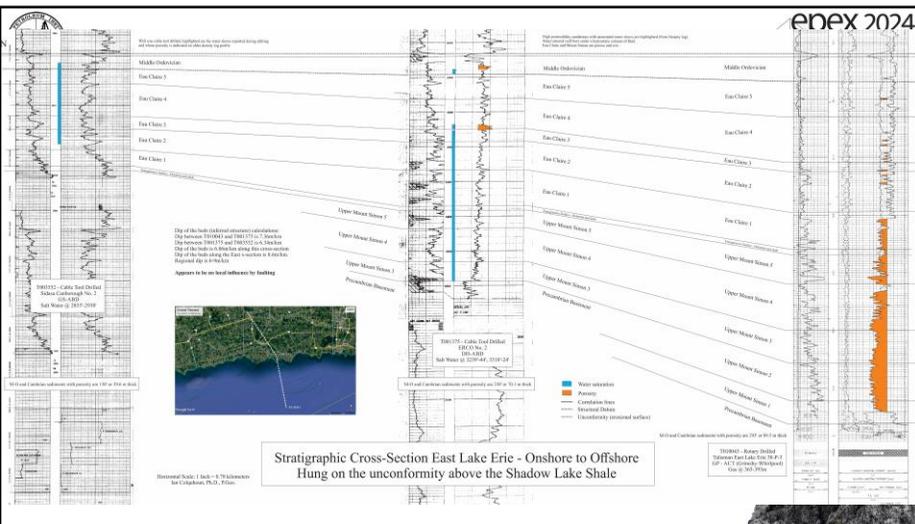
The stratigraphic cross-section shows a thickening of the Eau Claire and Mount Simon formations centered upon T001375. Thick, porous and water-saturated rocks are present within both the Eau Claire and Mount Simon formations along the Northshore of Lake Erie.



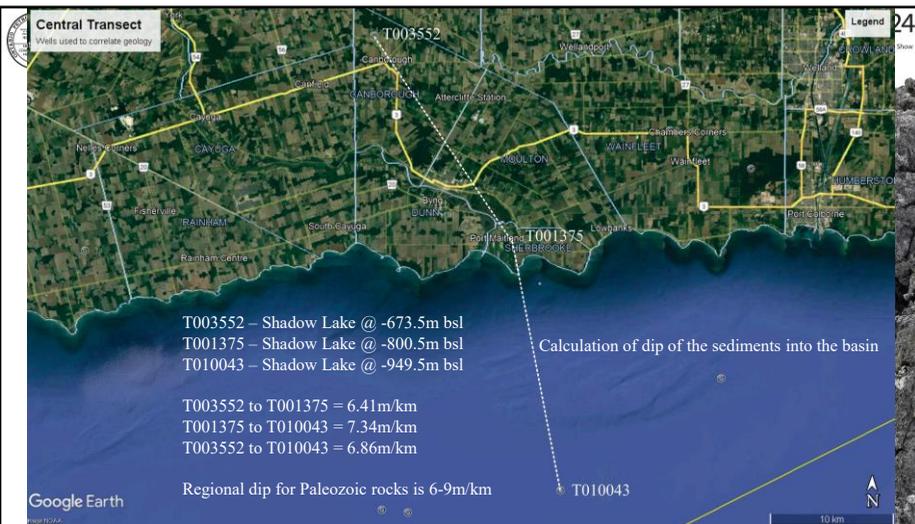
Slide 34: A north to south transect of wells from onshore to offshore Lake Erie. Their logs were used to pick formation tops, to examine stratigraphic changes, and to calculate the regional dip of the rocks into the Appalachian Basin.



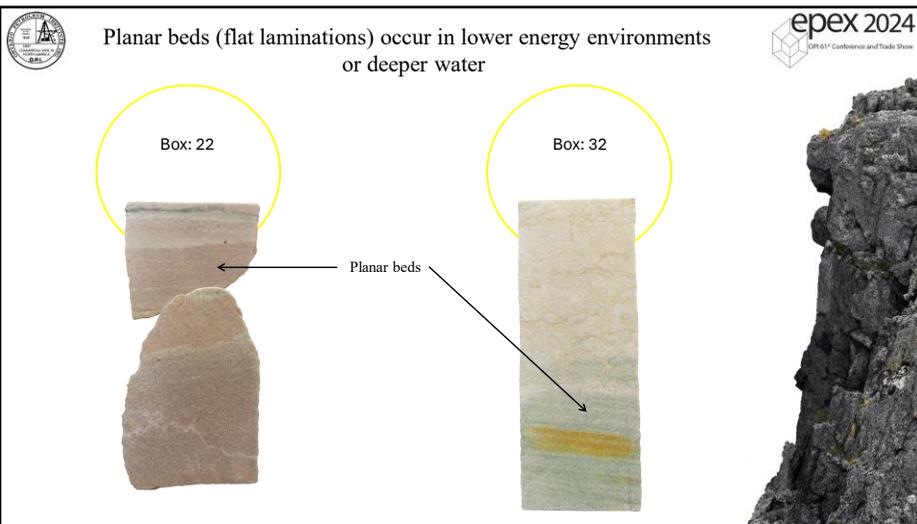
Slide 35: Eau Claire and Mount Simon units thicken into the Appalachian Basin and are water wet, thereby forming the deep saline aquifers of the Cambrian in SW Ontario.



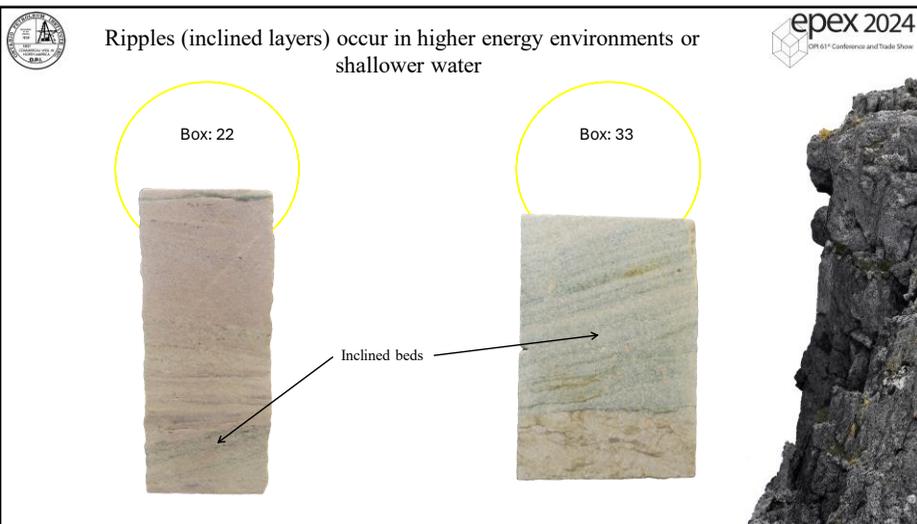
Slide 36: I used the formation top data to generate the dip of the M-O and Cambrian rocks into the Appalachian Basin. The calculated dip of these rocks is the same as previously published estimates, which is ~6-9m/km.



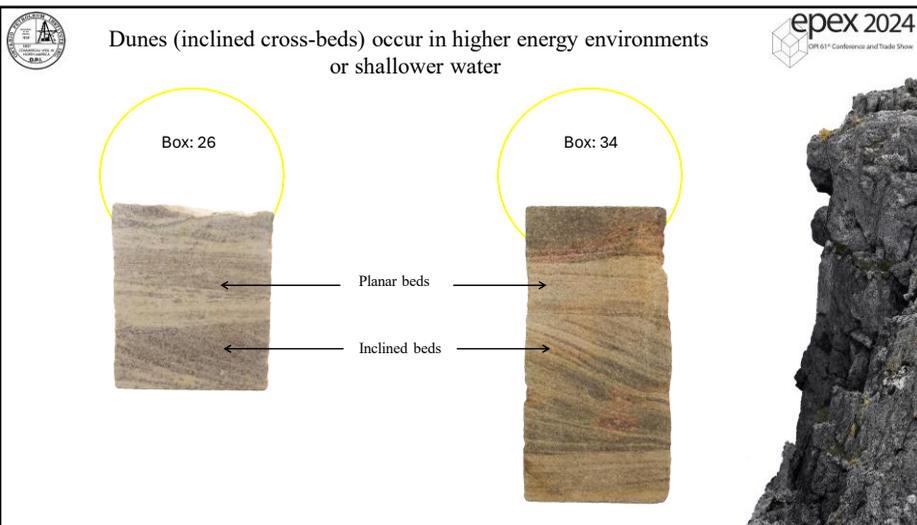
Slide 37: Planar beds or flat laminations that occur in lower energy or deeper water environments. Boxes 22, 32.



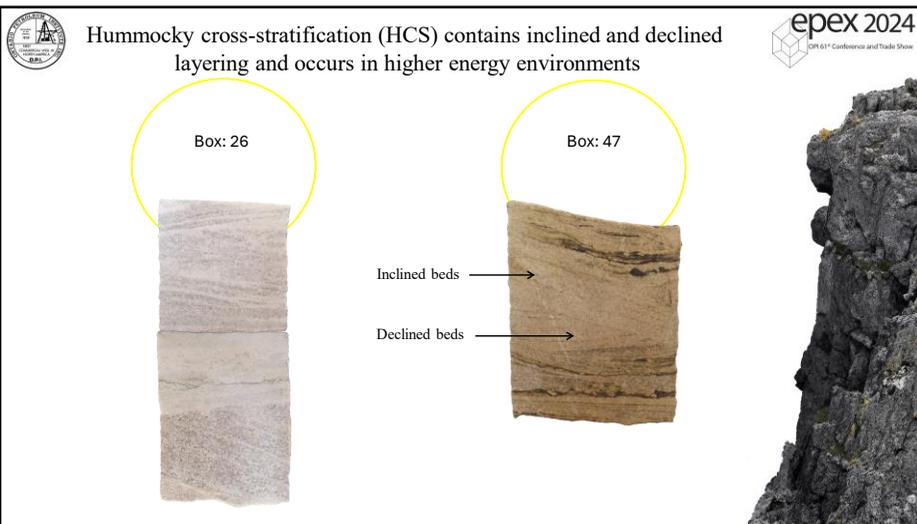
Slide 38: Ripples or inclined beds that occur in higher energy or shallow water environments. Boxes 22, 33.



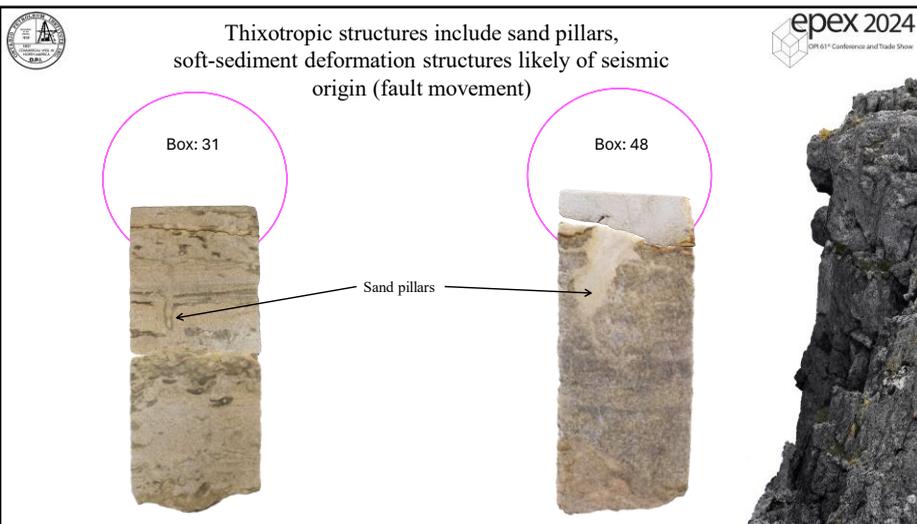
Slide 39: Dunes or inclined cross-beds occur in higher energy or shallow water environments. Boxes 26, 34.



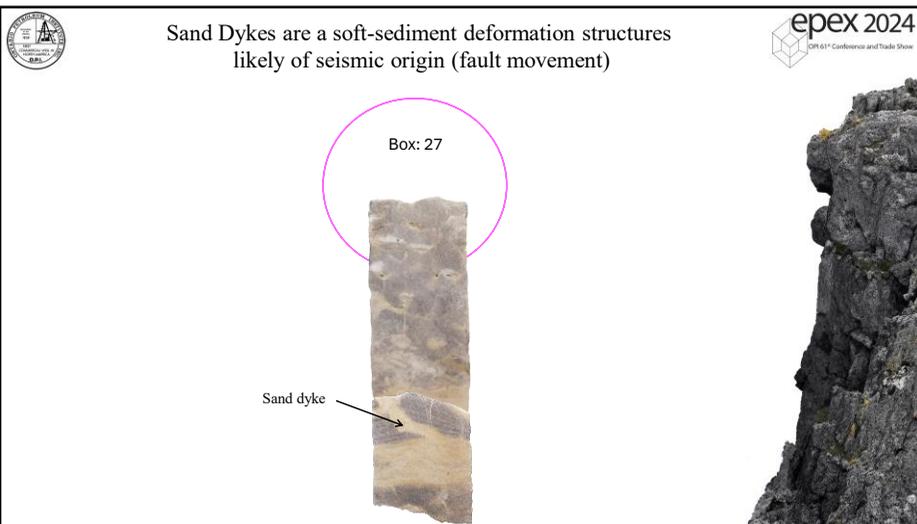
Slide 40: Hummocky cross-stratification (HCS) is identified by the presence of inclined and declined layering that sandwiches another layer, this typically occurs in very high energy depositional environments. Boxes 26, 47.



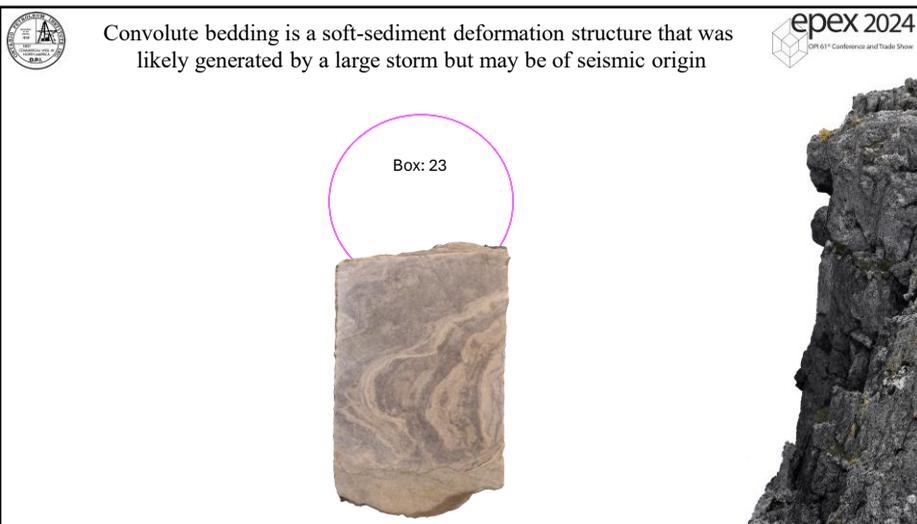
Slide 41: Thixotropic structures including sand pillars, sand dykes and convolute bedding, are examples of soft-sedimentary deformation structures, and many are likely of seismic origin during fault movements. In this slide we see sand pillars, a very small sand pillar structure on the left and a larger one on the right. Boxes 31, 48.



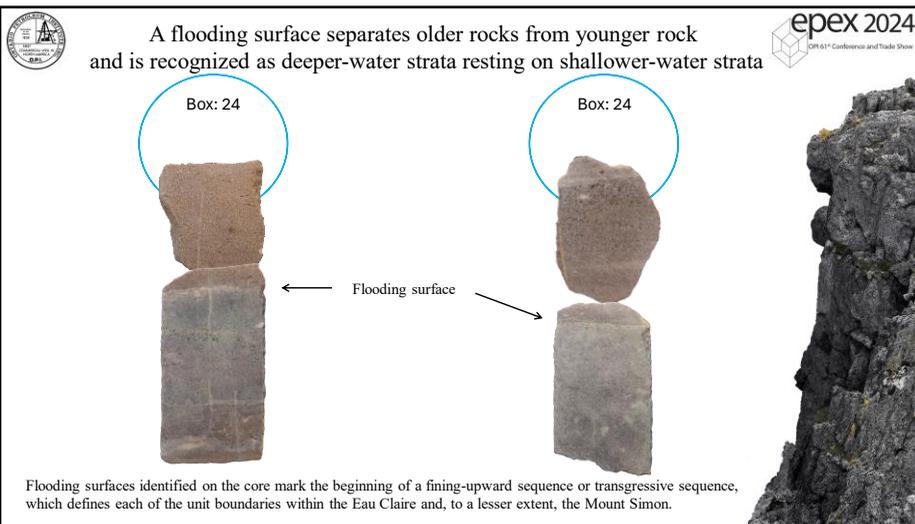
Slide 42: Here is an example of a sand dyke which is a classic soft-sediment deformation feature. Box 27.



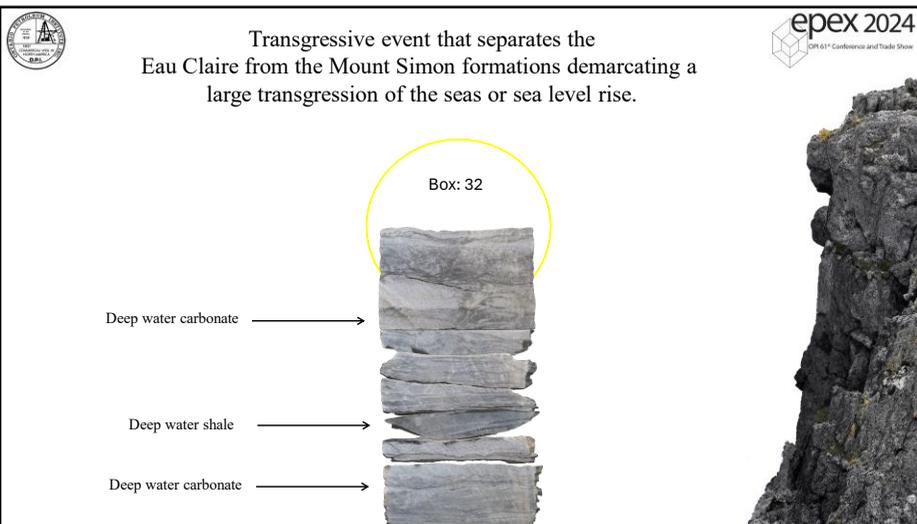
Slide 43: Here is an example of convolute bedding, another soft-sediment deformation structure. This feature may have formed following a large storm, algal mats became compressed into an accordion-like fashion and then turned onto their side. Box 23.



Slide 44: Flooding surface that marks the beginning of a fining upwards sequence or transgressive surface. The surface separates deeper water strata below, i.e., carbonates, from shallow water strata above, i.e., sandstones. Box 24.



Slide 45: Transgressive event is recorded by the deposition of deeper water carbonates followed by a deep-water shale. This transgressive event separates the Mount Simon Formation below from the Eau Claire Formation above. Box 32.



Slide 46: The unconformity that separates Cambrian sediments from the Middle Ordovician sediments. This is an erosional event that took place over a significant amount of time. Note the undulating surface between the layers. Box 21.

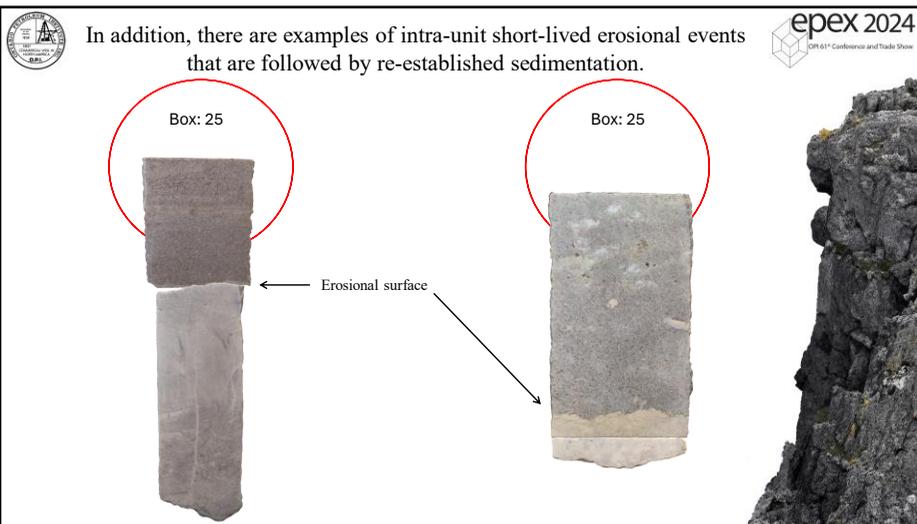
 An unconformity is a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.



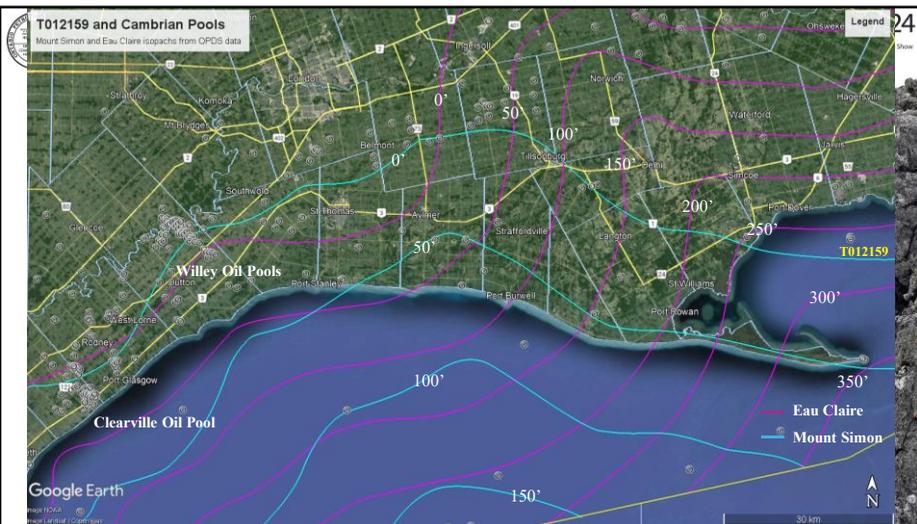
Box: 21



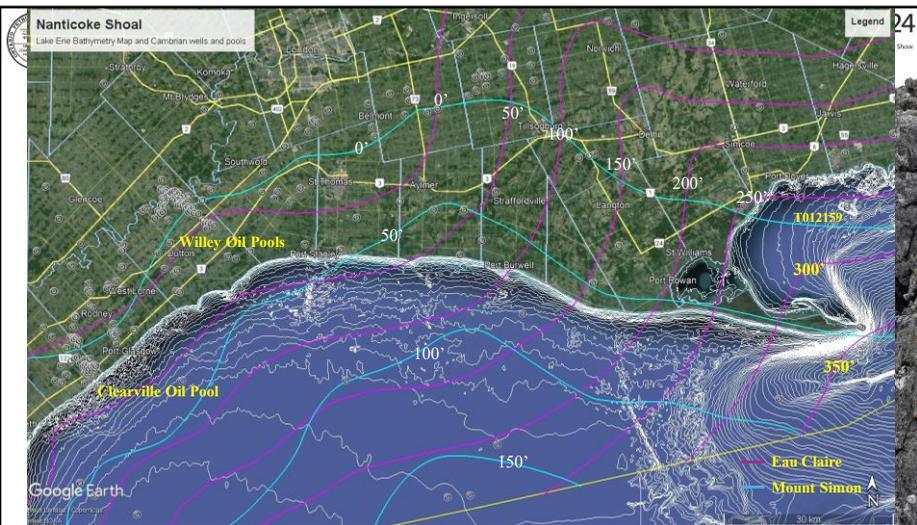
Slide 47: There are other short lived erosional events observed as irregular surfaces that separate different lithologies, here the carbonate rock at the bottom was eroded prior to deposition of the overlying sand. Box 25.



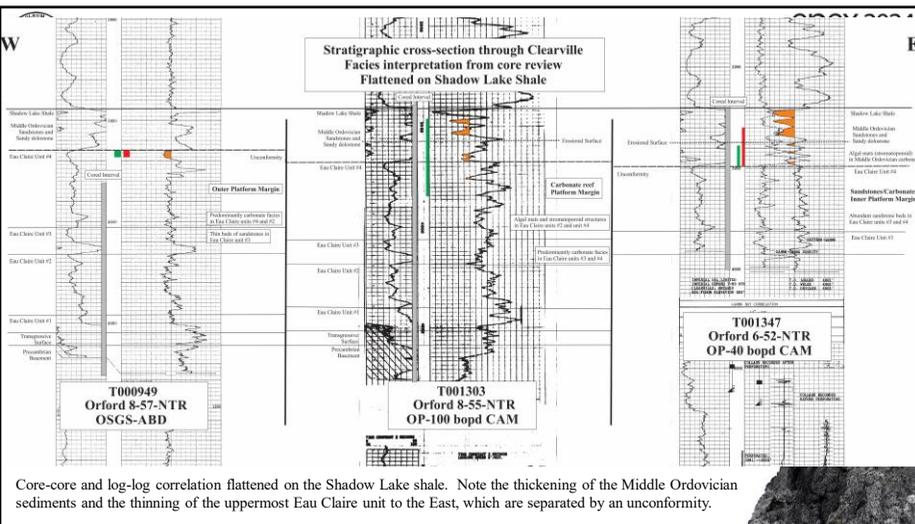
Slide 48: Isopach contours for the Eau Claire and Mount Simon formations generated using the geological data in OPDS. The isopach contours are labeled, along with the existing Cambrian-aged oil fields and the T012159 well. Thicker accumulations of Eau Claire, compared to Mount Simon, along the shoreline are the result of a significant sea level rise over the continent of Laurentia. Note the thickening of both the Eau Claire and Mount Simon formations towards the southeast portion of the map.



Slide 49: The same map with the bathymetry layer for Lake Erie to the study area map. Note that there is an increased depth of the lakebed where we observe an increased thickness of the Eau Claire and Mount Simon in the subsurface. Is this just a coincidence?



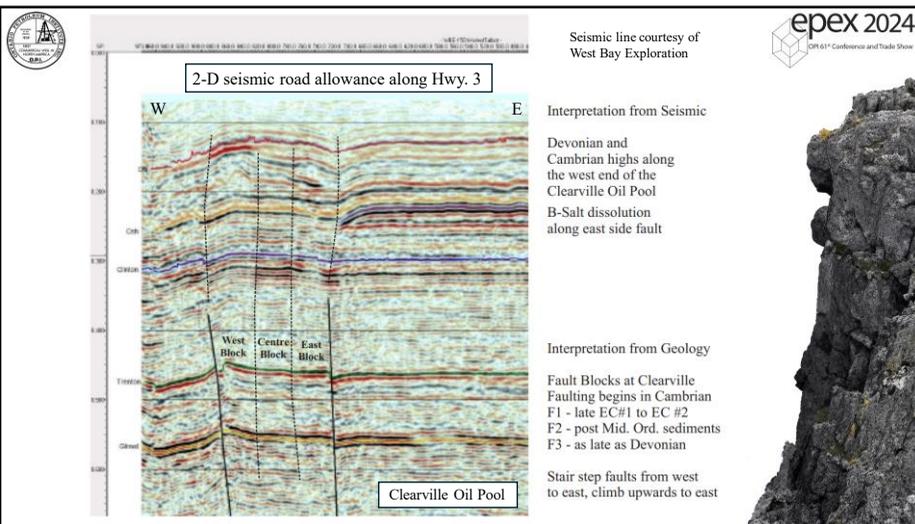
Slide 50: There is a lot to learn about the geology of the Cambrian and earliest part of the Middle Ordovician by mapping the sediments within an oil pool where there are several cores available, i.e., the Clearville Oil Pool. This is a stratigraphic cross-section hung on the unconformity above the Shadow Lake shale. There is a thickening of the Middle Ordovician sediments to the East, but not a lot can be interpreted for the Cambrian sediments below the unconformity. Depositional facies are interpreted such as Outer Platform Margin on the West side of the Clearville Oil Pool, Carbonate Reef Platform Margin in the center, and Inner Platform Margin on the East side, all based upon sedimentary features in the core. Three fault blocks are interpreted based upon the structural geology, relative thickening of the units, and the variable reservoir development across the pool.



Core-core and log-log correlation flattened on the Shadow Lake shale. Note the thickening of the Middle Ordovician sediments and the thinning of the uppermost Eau Claire unit to the East, which are separated by an unconformity.

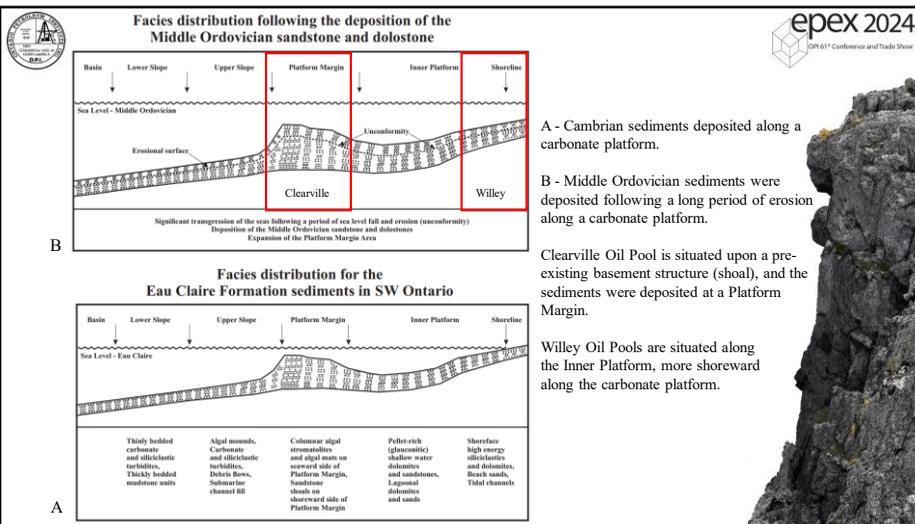


Slide 52: The apparent dip of the Cambrian structure on seismic is opposite to that shown on the preceding structural cross-section. This has been determined to be an artifact of seismic data. If you flatten the seismic on the Rochester Formation, the fault blocks are observed to be faulted upwards to the East, the same as that depicted on the preceding structural cross-section.





Slide 54: When we interpret the Middle Ordovician and Cambrian sediments with respect to sedimentary environments, we place the Clearville Oil Pool and structure along a Platform Margin and the sediments at the Willey Oil Pool much closer to the paleo-shoreline. Sediments at Clearville were deposited on a pre-existing basement high or shoal, while the sediments at Willey were deposited within very shallow depositional environments, such as upper shoreface and beach environment.



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LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
26:1023.99 to  
1026.99 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD59

FD60

FD61

↑1024.00

FD62

FD63

FD64

FD65

↑1025.00

FD66

FD67

FD68

FD69

↑1026.00

FD70

FD71

MINIROD

inch NOTES  
TO12159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

inch NOTES  
27:1026.99 to  
1029.99 m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

FD72

FD73

FD74

↑1027.00

FD75

FD76

FD77

↑1028.00

FD78

FD79

↑1029.00 FD80

MINI-FOOD

inch NOTES  
TO12159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

inch NOTES  
28: 1029.99 to  
1031.95 m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

FD81



SP82



NOT ANALYZED

↑1030.00

NOT ANALYZED



SP83



FD84



FD85

↑1031.00



SP86



1031.95m ↑

12

18

19



inch  
NOTES  
T012.159  
# 1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
29 : 1034.70 to  
1037.72 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 87

FD 88



↑1034.70m

FD 89

↑1035.00

FD 90



FD 91

FD 92

↑1036.00

FD 93



FD 94

FD 95

FD 96



↑1037.00



inch NOTES  
TO12159  
#1130  
OGSR LIBRARY www.ogsrlibrary.com  
cm

inch NOTES  
30: 1037.72 to  
1040.74 m  
OGSR LIBRARY www.ogsrlibrary.com  
cm



FD 97

FD 98

FD 99

\$1038.00

FD 100

FD 101

FD 102

FD 103

\$1039.00

FD 104

FD 105

FD 106

FD 107

\$1040.00



inch  
NOTES  
TO12159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
31: 1040.74 to  
1043.44m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

FD 108

FD 109

FD 110

FD 111

↑1041.00

FD 112

FD 113

FD 114

FD 115

↑1042.00

FD 116

FD 117

FD 118

↑1043.00

MINIROD



inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
32:1043.44 to  
1045.88 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD119

FD120

FD121

1044.00

FD122

FD123

FD124

1045.00

FD125

MINI-ROD

inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
33: 1045.88 to  
1048.22 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD126

FD127

FD128

↑ 1046.00

FD129

FD130

FD131

↑ 1047.00

FD132

FD133

↑ 1048.00

MINI-ROD

inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
34:1048.22 to  
1050.20 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD134

FD135

FD136

FD137

FD138

↑1049.00

FD139

FD140

FD141

↑1050.00

1050.20m

MINI-ROD

11  
12  
13  
14

inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
35:1050.30 to  
1053.33 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD142

FD143

↑1050.30M

FD144

FD145

FD146

↑1051.00

FD147

FD148

FD149

FD150

↑1052.00

FD151

FD152

↑1053.00

MINI-ROD

inch NOTES  
TO12159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

inch NOTES  
36:1053.33 to  
1055.61 m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

FD153

FD154

FD155

FD156

FD157

↑1054.00

FD158

FD159

FD160

↑1055.00



inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
37: 1055.61 to  
1057.93 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD161

FD162

↑ 1056.00

FD163

FD164

FD165

FD166

↑ 1057.00

FD167



inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
38: 1057.43 to  
1060.93 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD168

FD169

FD170 ↑1058.00

FD 171

FD 172

FD 173

↑1059.00 FD 174

FD 175

FD 176

FD 177

↑1060.00

FD 178

MINIFROD

inch  
NOTES  
TO12159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
39:1060.93 to  
1063.20 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 179

1



FD 180

↑1061.00

FD 181

FD 182



FD 183

FD 184

↑1062.00



FD 185

↑1063.00



11

18

17

20



inch  
NOTES  
T012159  
# 1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
40:1063.20 to  
1065.51 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 186

FD 187

FD 188

FD 189

↑1064.00

FD 190

FD 191

FD 192

↑1065.00

21

22

23

24

Clayey



inch  
NOTES  
TO12159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
41: 1065.51 to  
1067.75 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 193

FD 194

FD 195

FD 196

↑1066.00

FD 197

FD 198

FD 199

FD 200

↑1067.00

1067.75M↑

25  
26  
27

80011



INCH NOTES  
TO12159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

INCH NOTES  
42:1067.80 to  
1070.11 m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

FD201

FD202

↑1067.80m

FD203

↑1068.00

FD204

FD205

FD206

FD207

↑1069.00

FD208

FD209

↑1070.00

MINI-ROD

2 1 0 9 8 7 6 5 4 3 2 1 0 0

inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
43:1070.11 to  
1072.38m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD210

FD211

FD212

FD213

↑1071.00

FD214

FD215

FD216

↑1072.00

S

9

7

8

60-415



inch  
NOTES  
T012159  
#1130  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
44:1072.38 to  
1074.70m  
OGSR LIBRARY  
www.ogsrlibrary.com  
cm



inches  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inches  
NOTES  
45: 1076.80 to  
1079.81m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 225

FD 226

FD 227

↑1076.80m

FD 228

↑1077.00

FD 229

FD 230

↑1078.00

FD 231

FD 232

FD 233

FD 234

↑1079.00

MINI-ROD

Box 45

inch  
NOTES  
T012159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
46: 1079.81 to  
1082.81 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 235

FD 236

↑1060.00 FD 237

FD 238

FD 239

↑1031.00 FD 240

FD 241

FD 242

FD 243

↑1082.00

5

3

2

2

Box 4



inch  
NOTES  
TO12159  
#1130  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

inch  
NOTES  
47:1082.81 to  
1085.82 m  
OGSR  
LIBRARY  
www.ogsrlibrary.com  
cm

FD 244

FD 245

FD 246

↑1083.00

FD 247

FD 248

FD 249

↑1084.00

FD 250

FD 251

FD 252

↑1085.00

MINI-ROD

inch  
NOTES  
T012159  
#1130  
OGSR LIBRARY  
www.ogstrlibrary.com  
cm

inch  
NOTES  
48: 1085.82 to  
1088.81 m  
OGSR LIBRARY  
www.ogstrlibrary.com  
cm

FD 253

FD 254

FD 255

↑1086.00 FD 256

FD 257

FD 258

↑1087.00

FD 259

FD 260

↑1088.00

13

14

15

16

13

