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OPI 61st Conference and Trade Show

Core Workshop

Middle Ordovician and

Cambrian-aged sediments,

Southwestern Ontario

Ian Colquhoun

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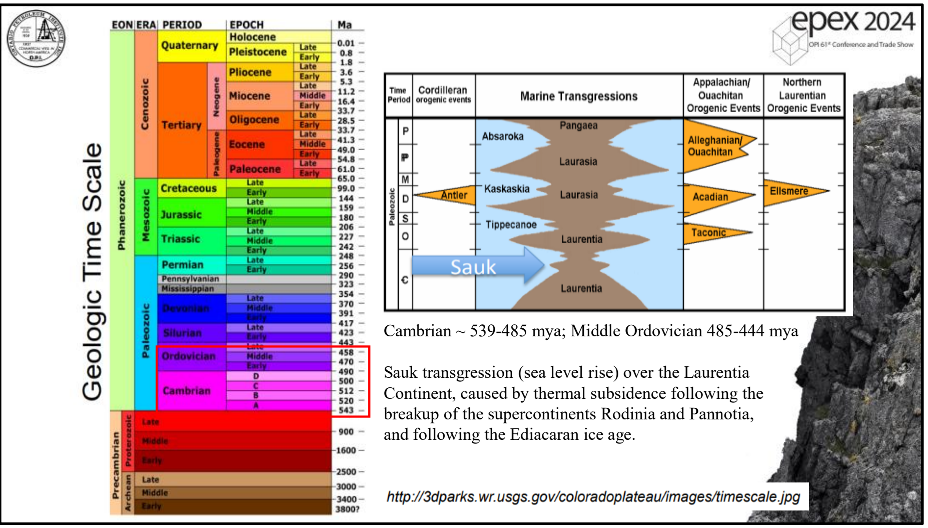
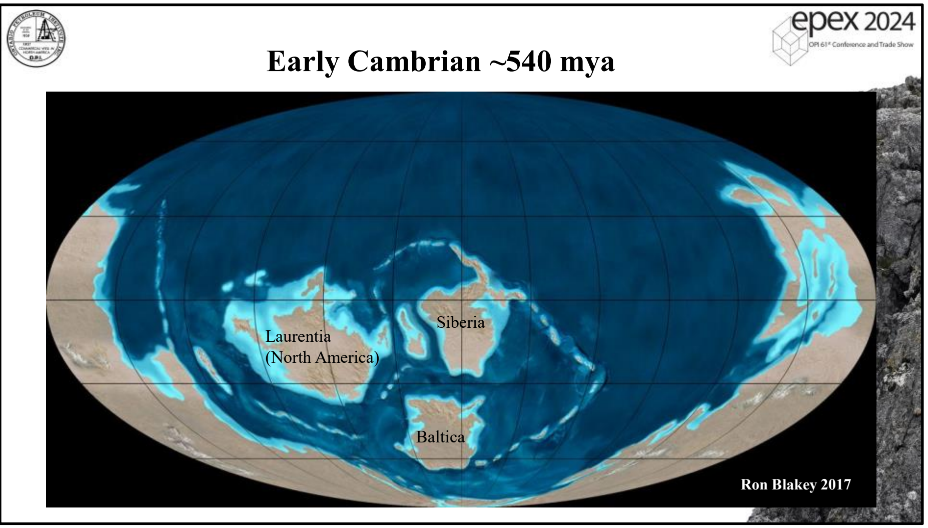
Middle Ordovician and Cambrian-aged sediments, Southwestern Ontario

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

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

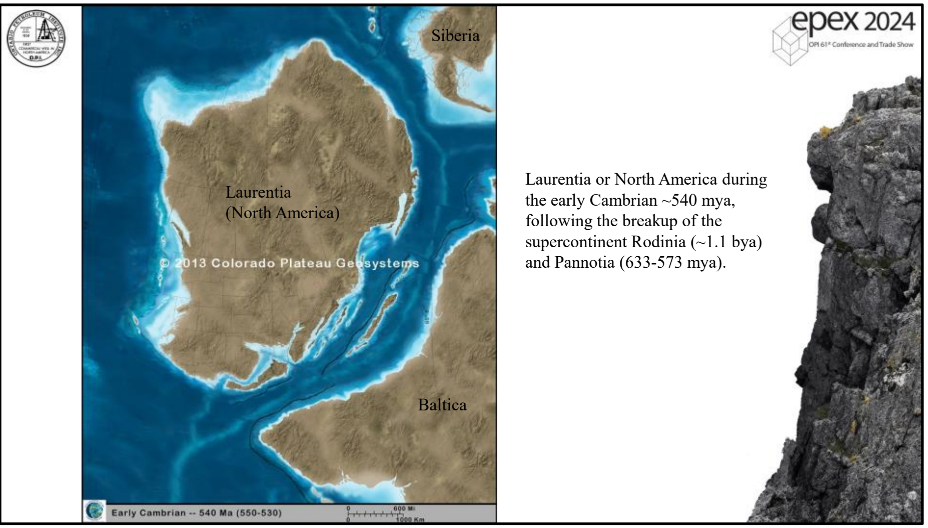


Slide 2: With respect to North America, the Cambrian began ~539 mya and continued until 485 mya, which was followed by the Middle Ordovician that continued until 444 mya. The Sauk Transgression, named after a significant sea level rise over the continental land mass of Laurentia (North America), led 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.

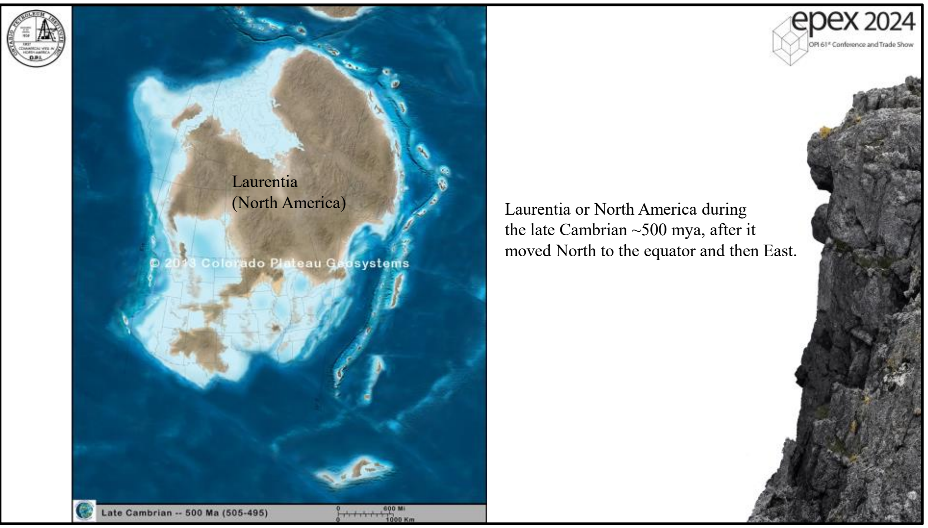


Slide 3: Here we see the position of the continents of Laurentia (North America), Siberia and Baltica during the Early Cambrian, ~540 mya. The continents were located south of the equator and began to move away from each other following the breakup of the supercontinents.

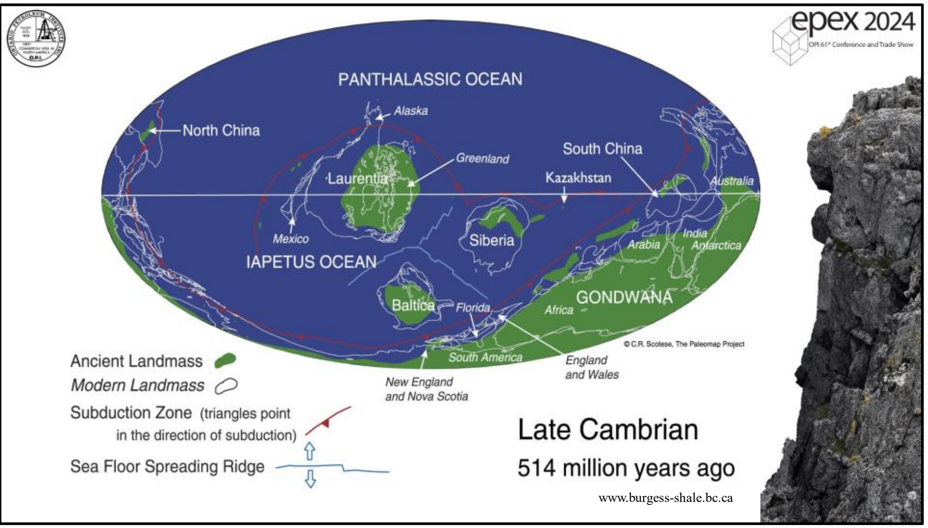
Slide 4: A close-up of Laurentia during the Early Cambrian, ~540 mya. Note the separation of Laurentia from the continents of Baltica and Siberia that began to drift north towards the equator.



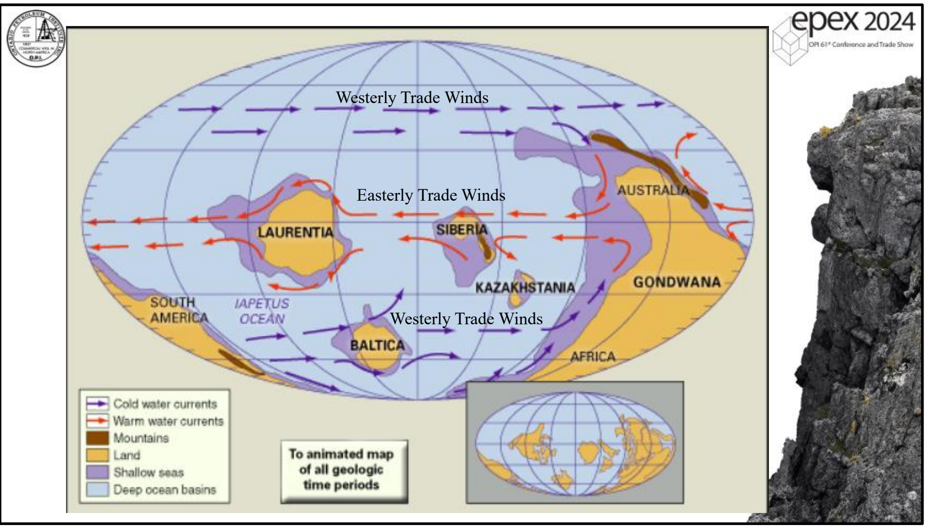
Slide 5: A close-up of Laurentia during the Late Cambrian, ~500 mya, following its movement North to the equator and then its movement to the East. Note the inundation of the seas along the continental margins.



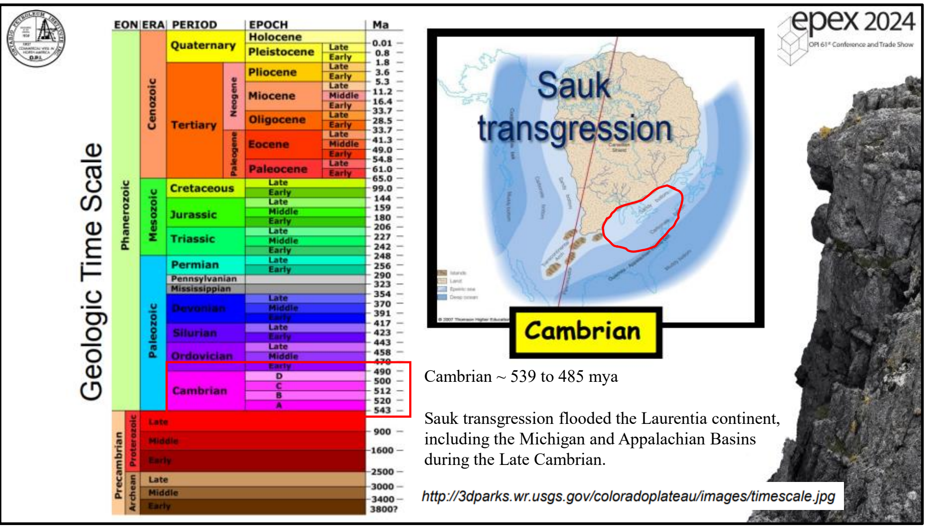
Slide 6: A snapshot of the continents at ~514 mya, Laurentia is at the equator and moving East along with the continents of Baltica and Siberia. Note their position within the Panthalassic and Iapetus oceans.



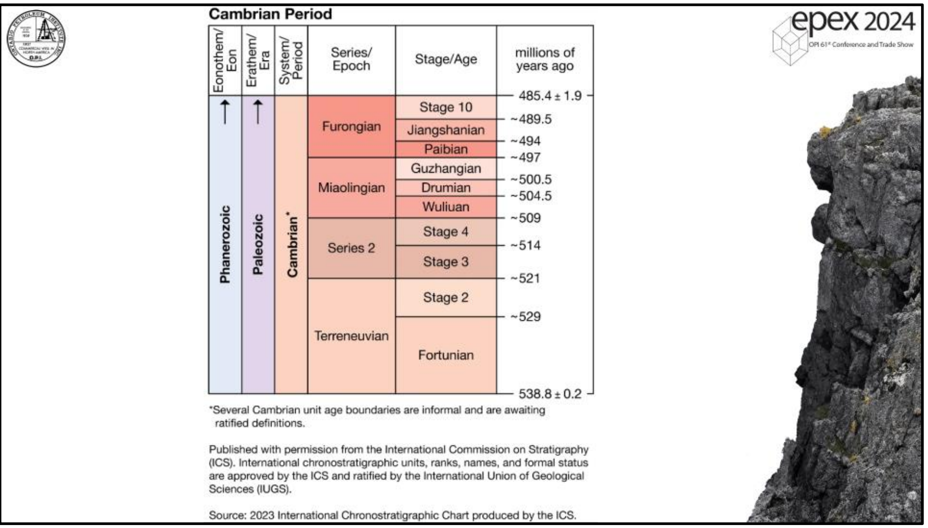
Slide 7: The continent of Laurentia was inundated by easterly trade winds that formed along the equator which dictated the track of storms generated from the extensive Panthalassic and Iapetus Oceans.



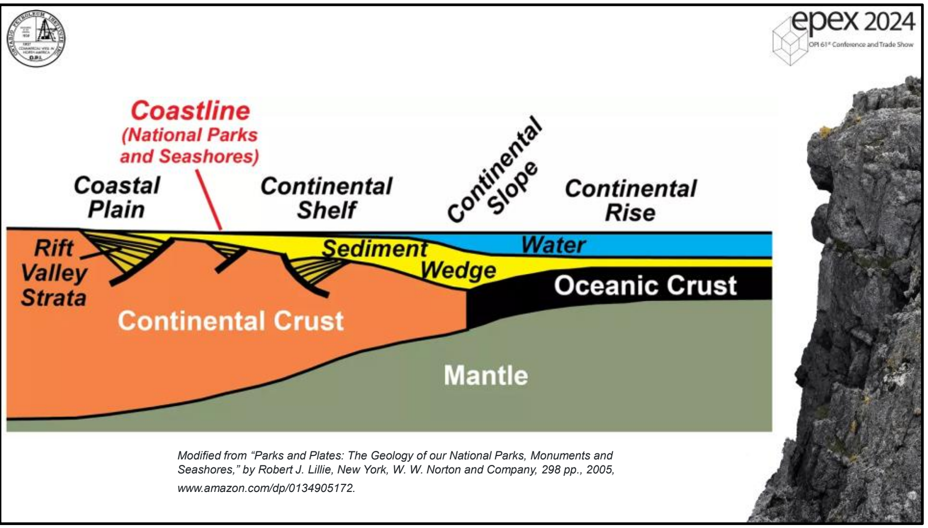
Slide 8: The Sauk Transgression was responsible for the flooding of coastal Laurentia and the deposition of Cambrian-aged sediments within the Michigan and Appalachian Basins, this area is highlighted in the red circle.

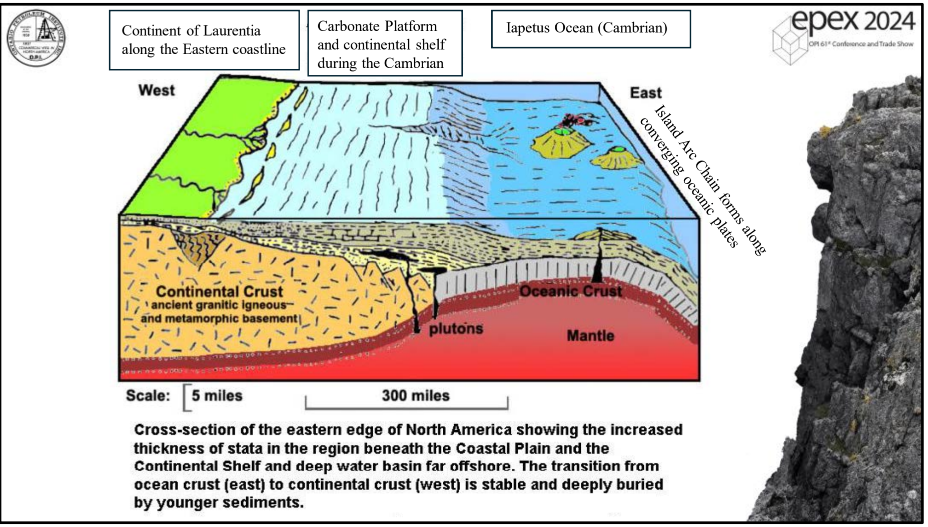


Slide 9: The Cambrian Period is being studied in detail today and these studies have proposed age boundaries for several stratigraphic units. These units are awaiting formal definitions that will need to be ratified by the International Commission on Stratigraphy (ICS).

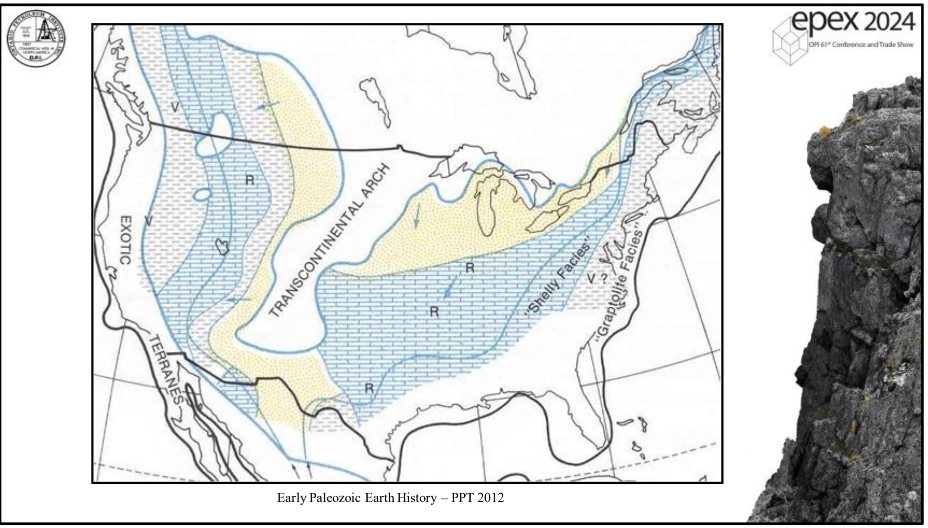


Slide 10: A cartoon of the geology for a continental shelf, which was the product of a passive continental margin during the Cambrian. A continental shelf was present on both the Eastern and Western coastlines of the Laurentian continent.

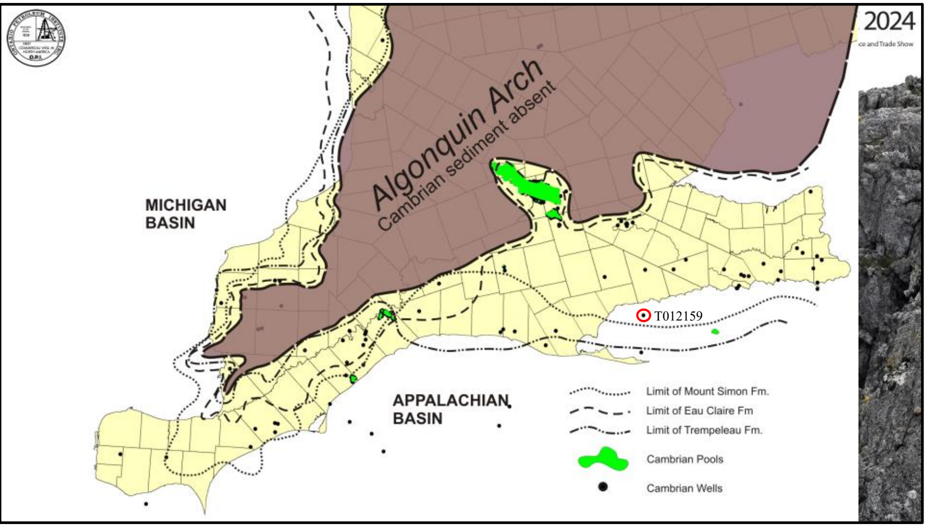




Slide 11: A cartoon of the passive continental margin during the Cambrian along Eastern Laurentia showing the broad carbonate platform that extends outward towards the deeper parts of the carbonate shelf and the Island Arc chain. The Island Arch chain was created by the subduction of an oceanic plate 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.

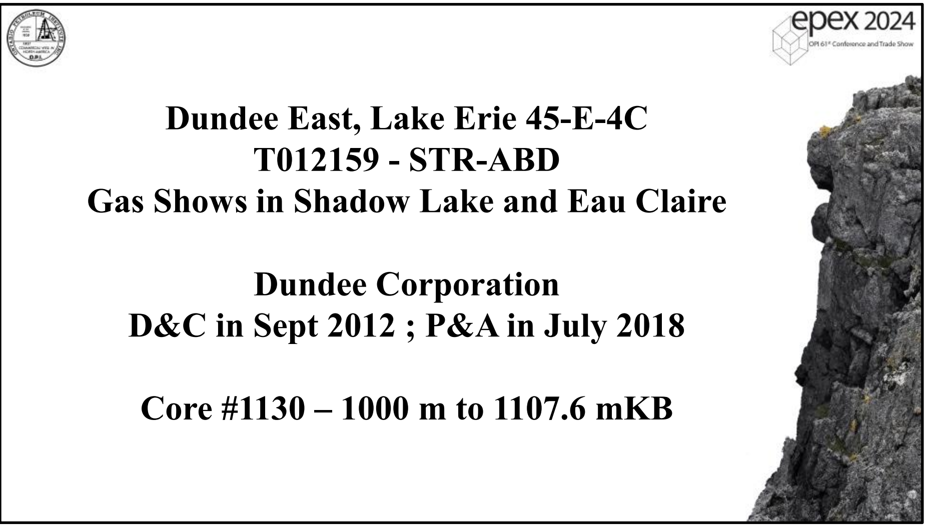


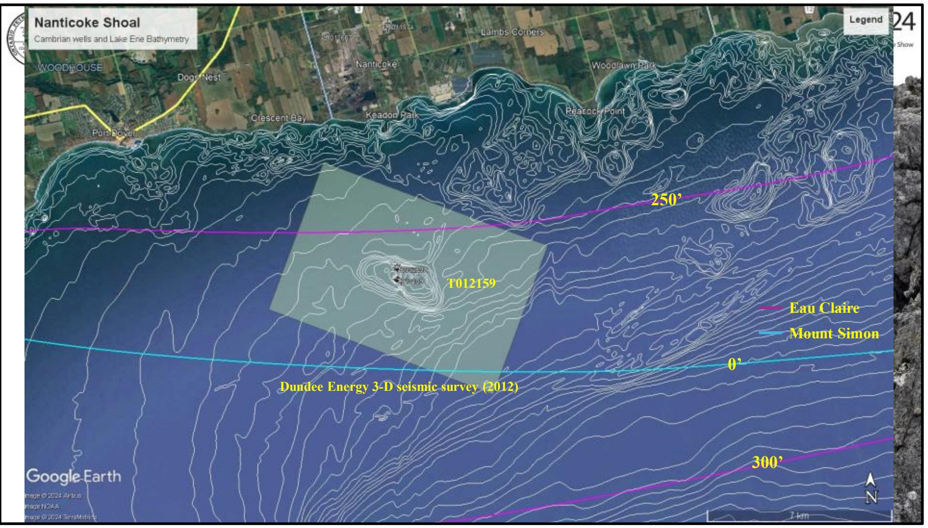
Slide 12: North America paleogeography during Cambrian time, the transcontinental arch stretches from Arizona northeast into Canada and divides the Laurentian continent. Depositional facies along the Eastern Laurentia continent includes sandstones near the paleo-shoreline, a broad area of limestones,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



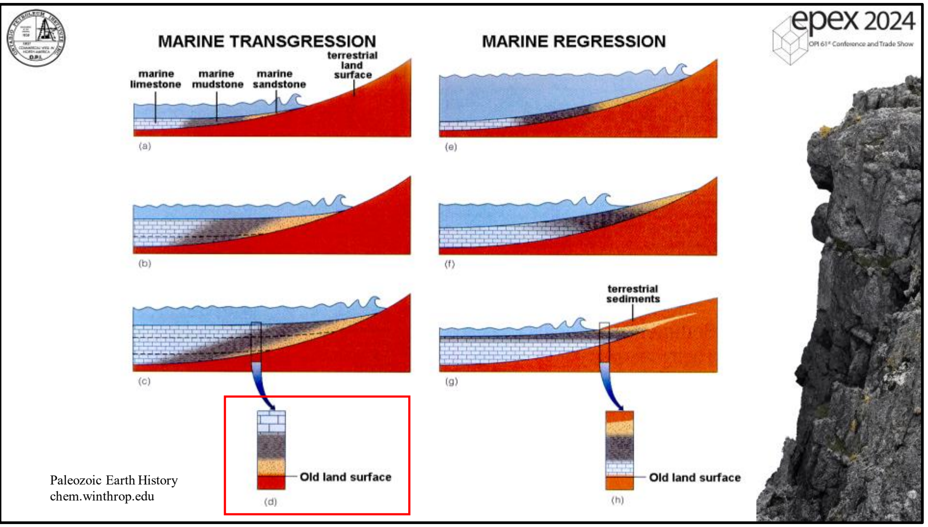
Slide 13: Today, the Cambrian sediments pinch out against the Algonquin Arch. This map shows the depositional limits for the Eau Claire, Mount Simon and Trempleau formations generated from data within OPDS. Our focus is on the geological description of the Middle Ordovician and Cambrian-aged sediments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

Slide 14: Slide is annotated.





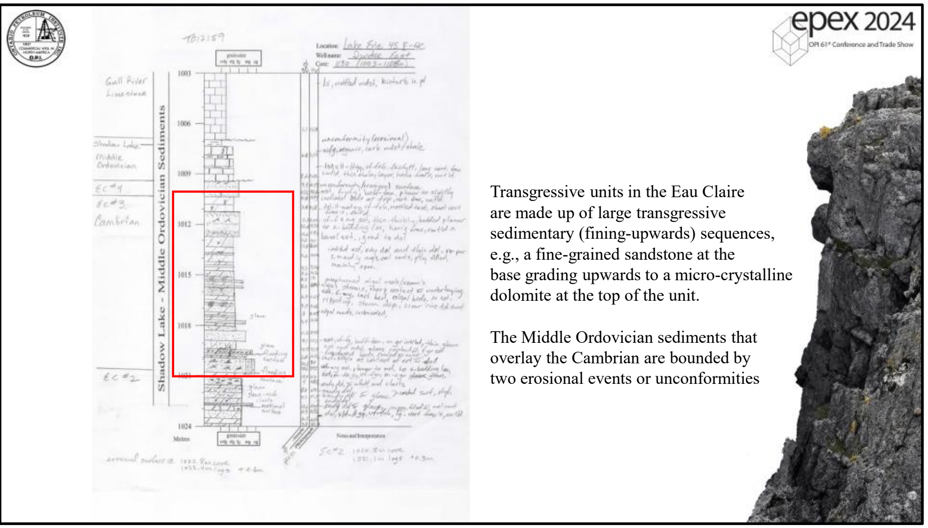
Slide 15: Dundee Energy shot a large 3-D seismic survey in 2012 over the Nanticoke Shoal, a well-known structural feature on the lakebed of Lake Erie, offshore Nanticoke. The shoal was identified as a structural high and a potential horst block structure reflected in the Paleozoic rocks below. Dundee 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.



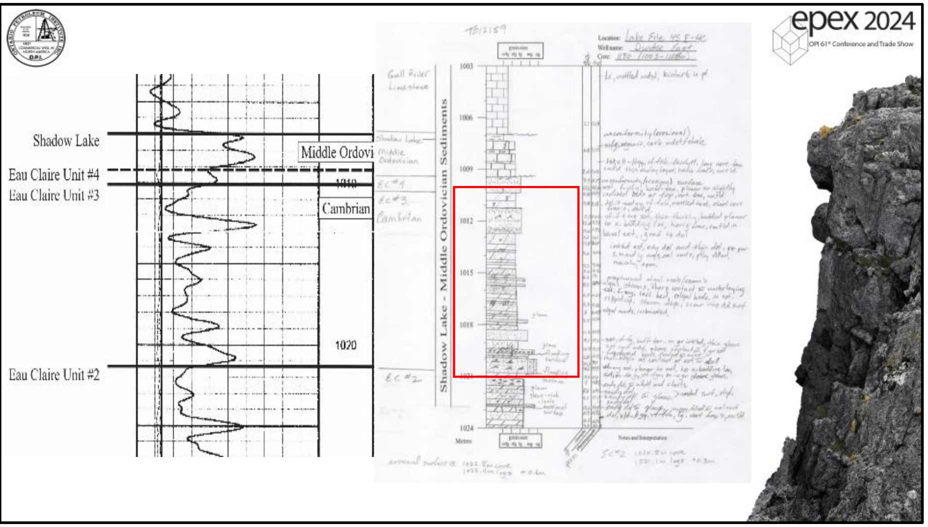
Slide 16: For this core workshop, I have described the geology of the Middle Ordovician and Cambrian sediments in core 1130 based upon a transgressive sequence or cycles of sedimentation, the image on the left-hand side of this slide. A transgressive sequence is depicted as a coarser-grained sandstone, 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.

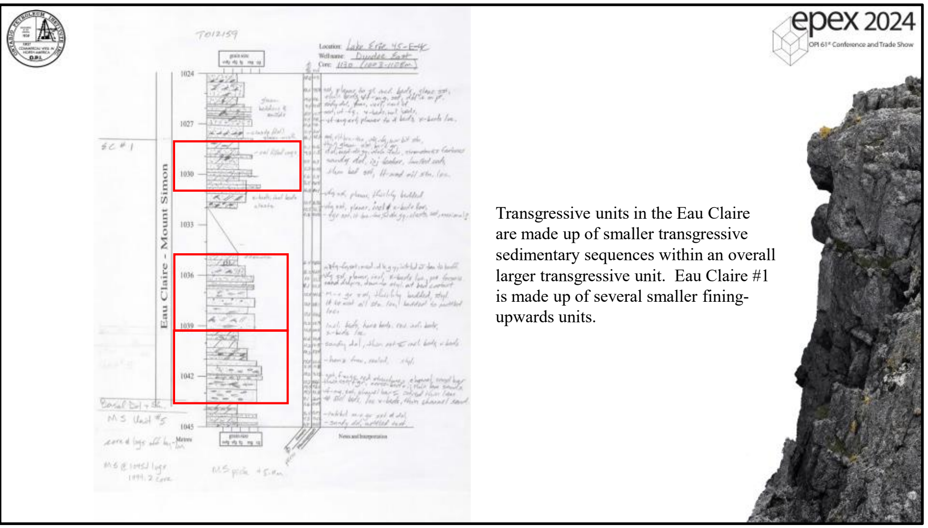
Slide 17: Slide is annotated.



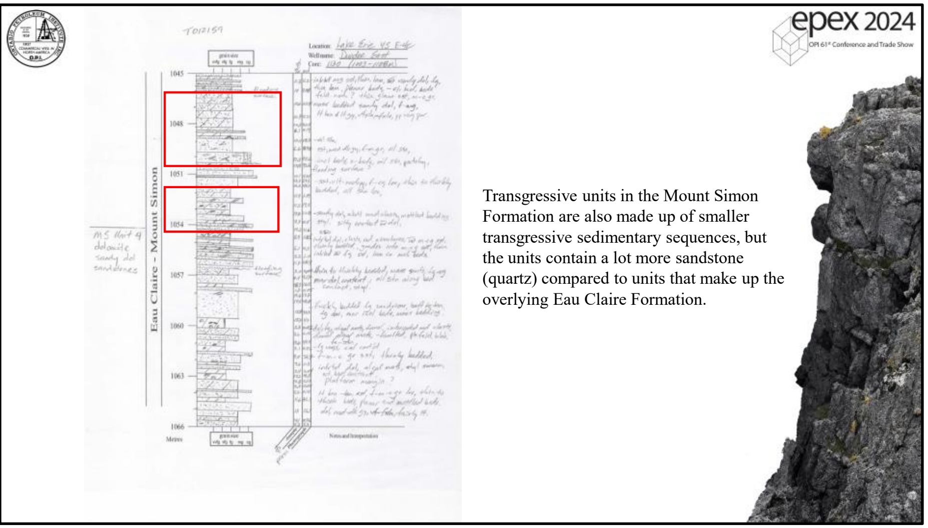
Slide 18: Fining upwards sequence for Eau Claire #3 on the lithology and the geophysical logs. Note the high gamma sandstone at the bottom that grades upwards to low gamma and fine-grained dolomite at the top of the unit.



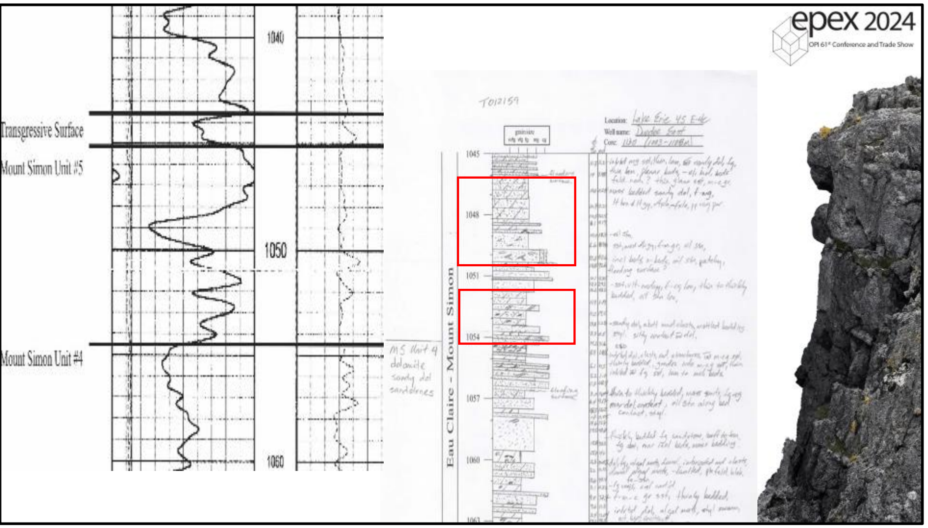
Slide 19: Slide is annotated.



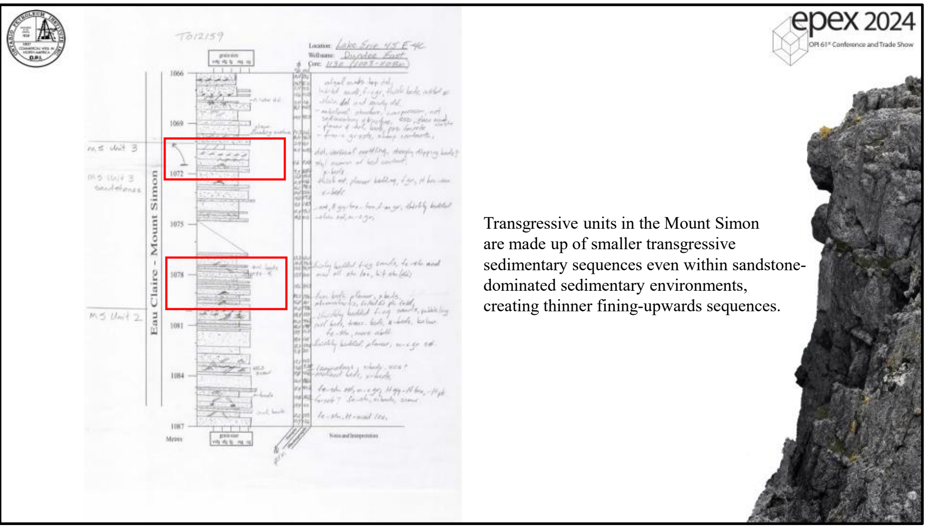
Slide 20: Slide is annotated.



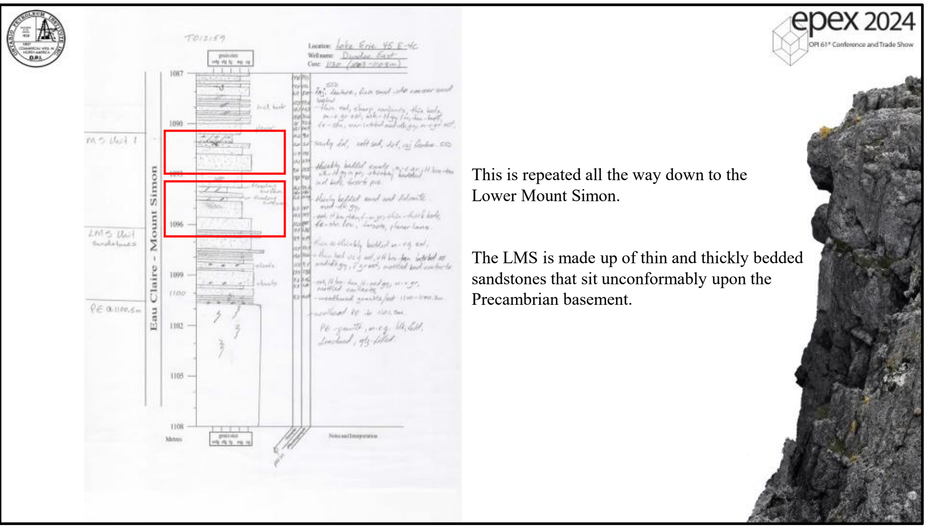
Slide 21: Fining upwards sequence for Mount Simon #5. High gamma sandstone at the base that grades upwards to low gamma and finer-grained sandy dolomite at the top of the unit.



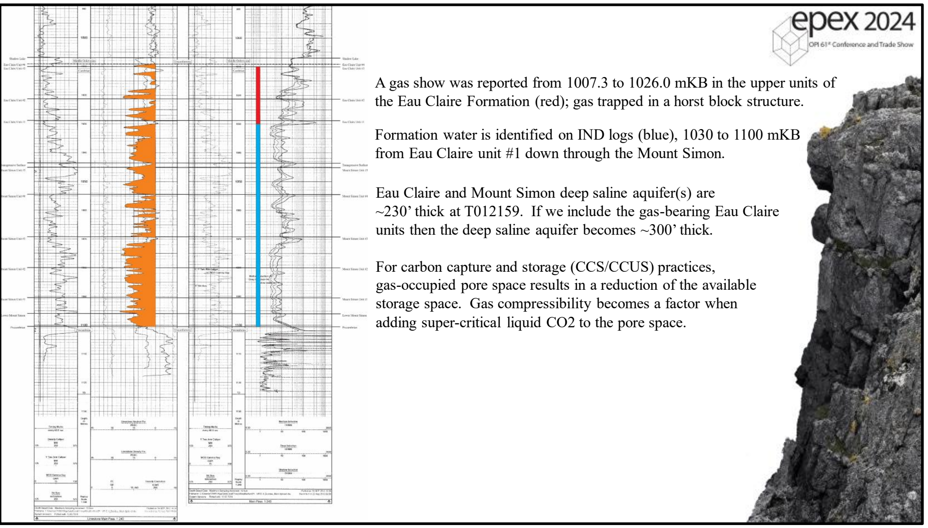
Slide 22: Slide is annotated.



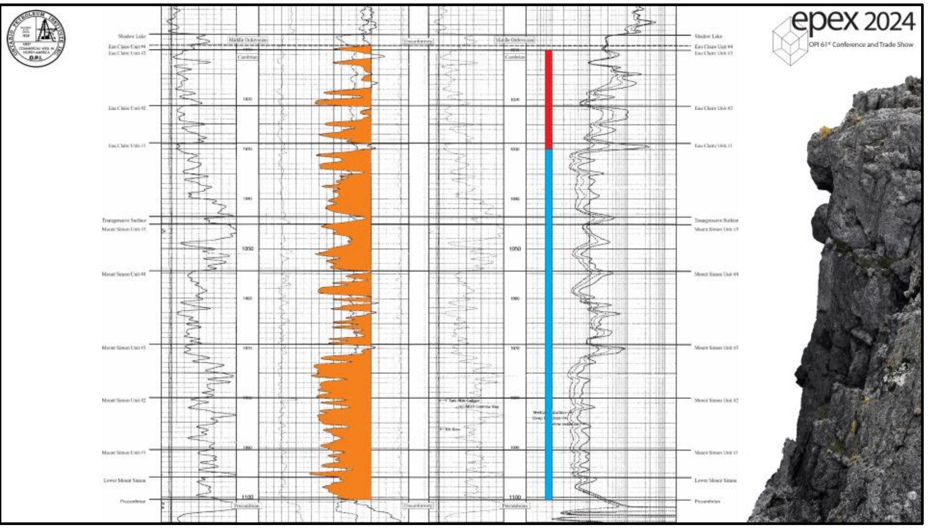
Slide 23: Slide is annotated.

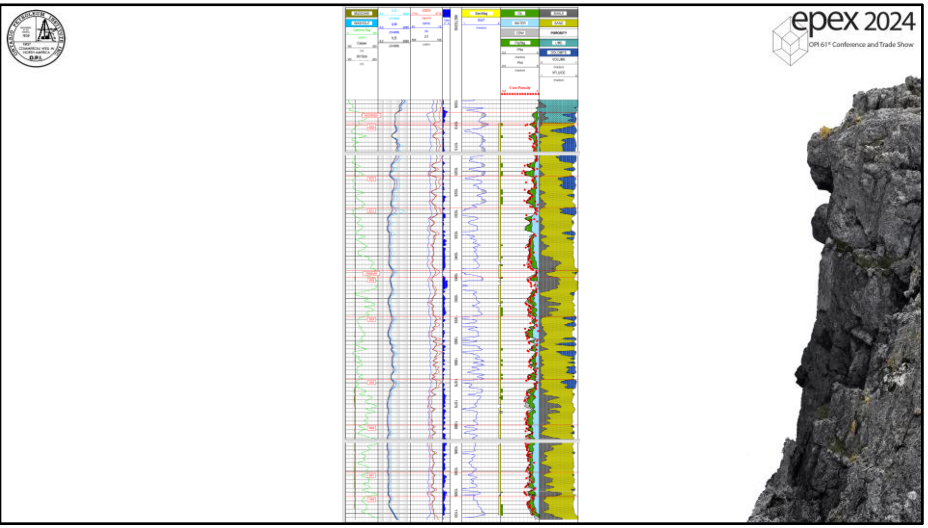


Slide 24: Slide is annotated.

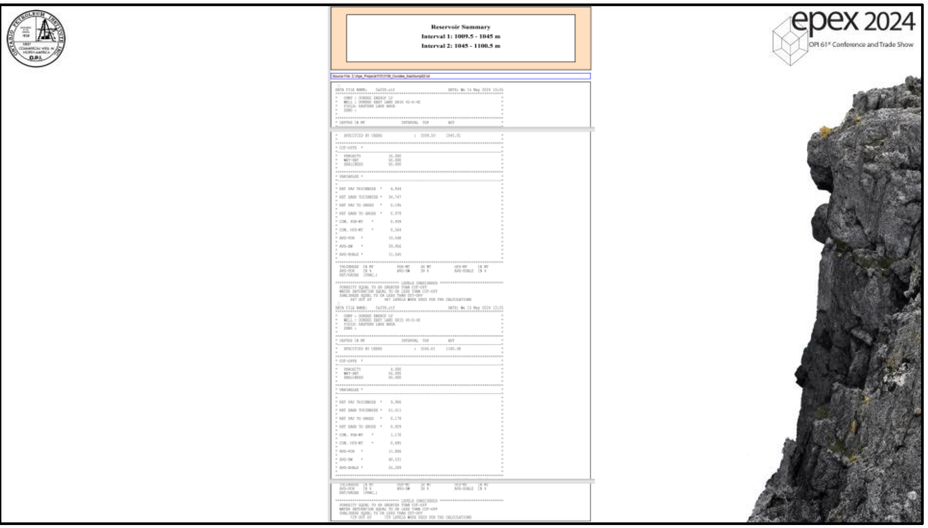


Slide 25: The Middle Ordovician and Cambrian units are identified on the geophysical logs of T012159 along with the gas- and water-bearing portions of the well.





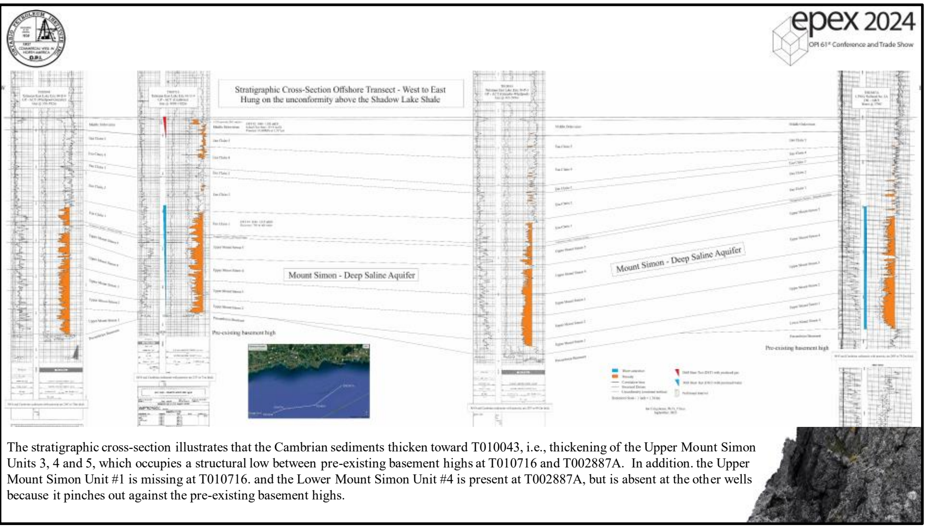
Slide 26: Petrophysical analysis of the geophysical logs from T012159. Baker Hughes ran a stochastic petrophysical log analysis using the data from the porosity and resistivity logs. There are a couple high-level items to mention, the effective porosity and movable hydrocarbons (dark green) are much 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.



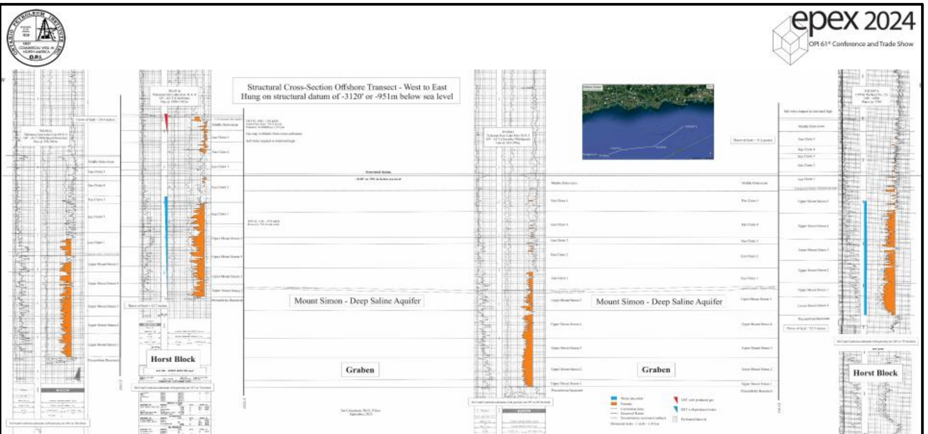
Slide 27: These are the parameters used to generate a reservoir summary. I examined the core analyses and selected a permeability cut off ~1 md to determine the porosity cutoffs to be used in the petrophysical analysis. For the Eau Claire, the porosity cutoff is 10% and for the Mount Simon the porosity cutoff is 4%, therefore porosity below these cutoffs is not expected to contribute to the production of fluids. If the well won't give up fluid, then it surely will not accept any either. There are many items on the petrophysical analysis that we can discuss during the walk-around portion of this core presentation.

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.

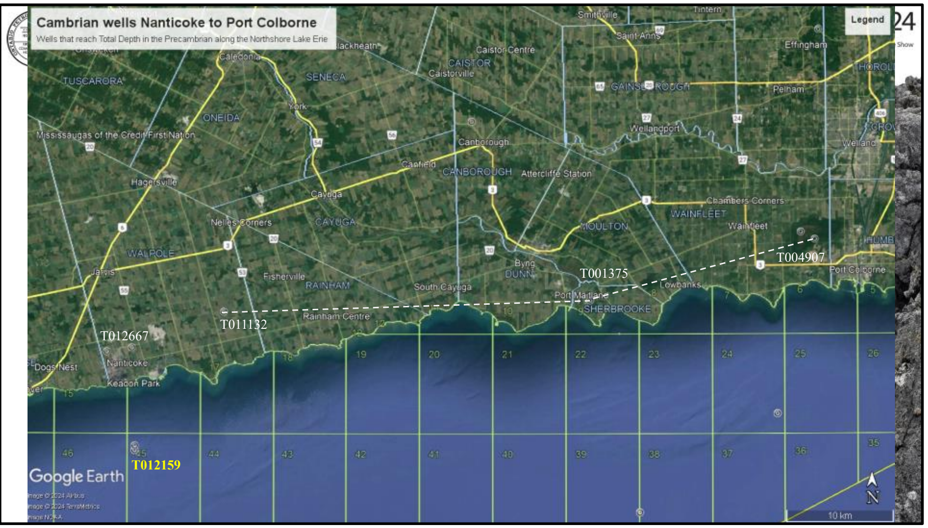


Slide 30: Slide is annotated.

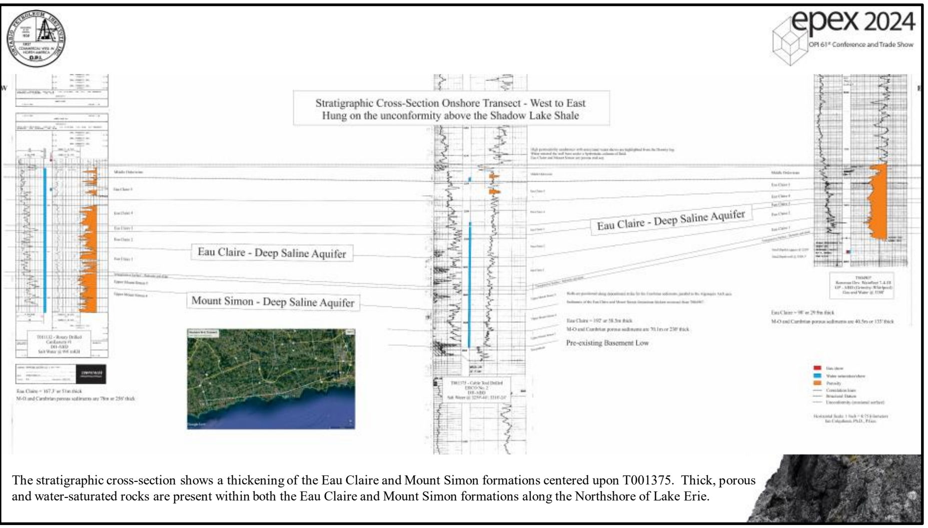


Normal fault movement around pre-existing basement highs resulted in the formation of two horst blocks, at T010716 and T002887A, and a graben that is centered upon T010043. Thickening of the Eau Claire and the lower units of the Upper Mount Simon at T010043 occurred during early basin development. Pre-existing basement highs and syn-depositional fault movement affected sediment thickness in both the Eau Claire and the Mount Simon formations.

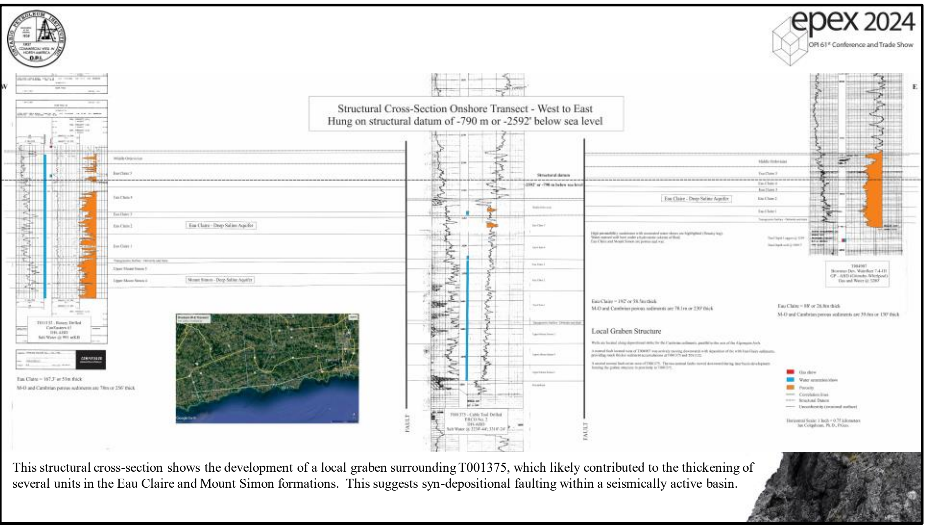
Slide 31: A three well transect along the Northshore of Lake Erie used to correlate the sedimentary units but deposited in shallower sedimentary environments.



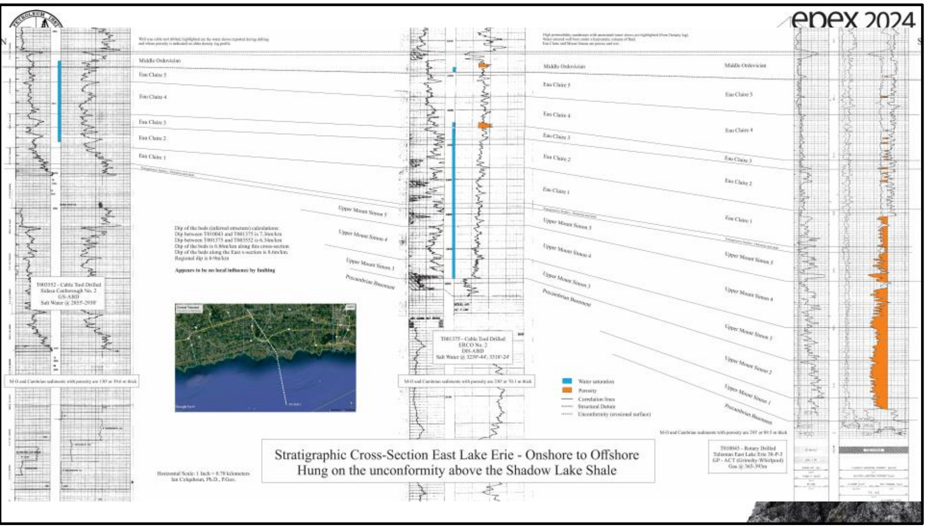
Slide 32: Slide is annotated.



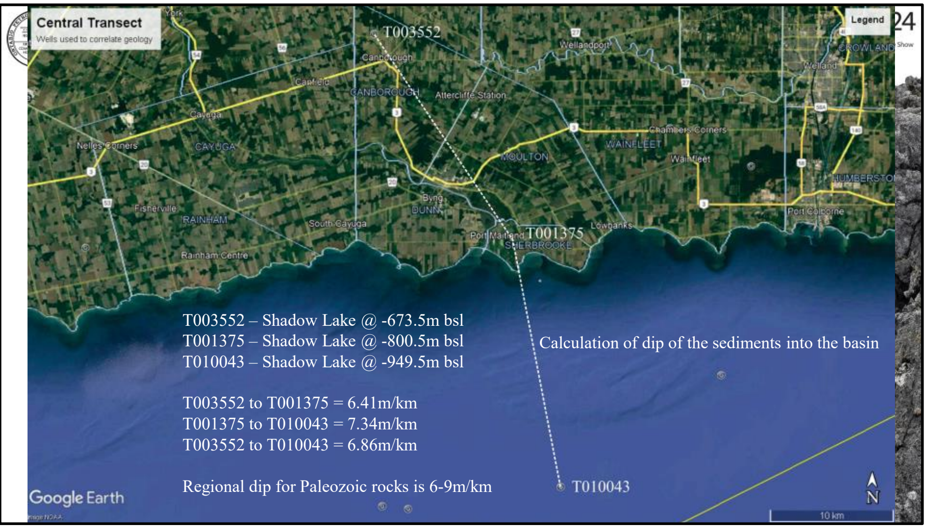
Slide 33: Slide is annotated.



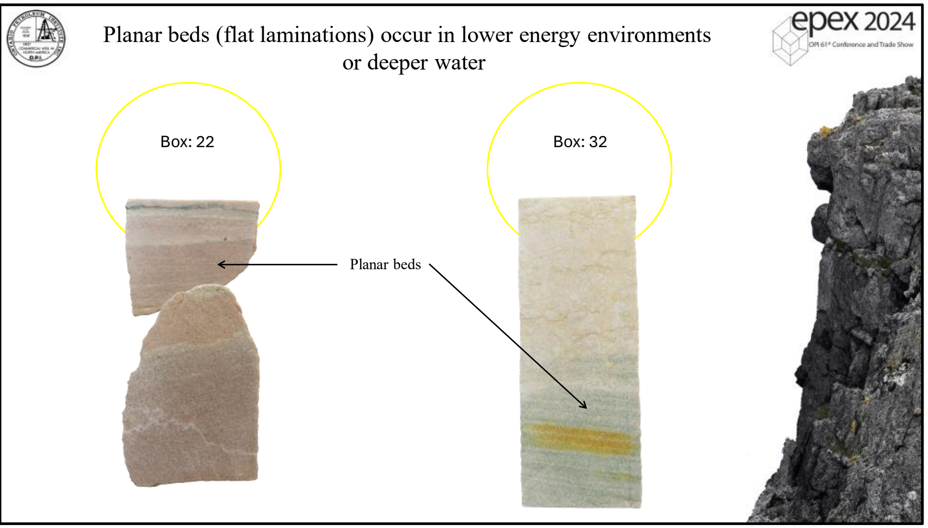
Slide 34: A north to south transect of wells from onshore to offshore Lake Erie. Their logs were used to pick formation tops, to examine stratigraphic changes, and to calculate the regional dip of the rocks into the Appalachian Basin.



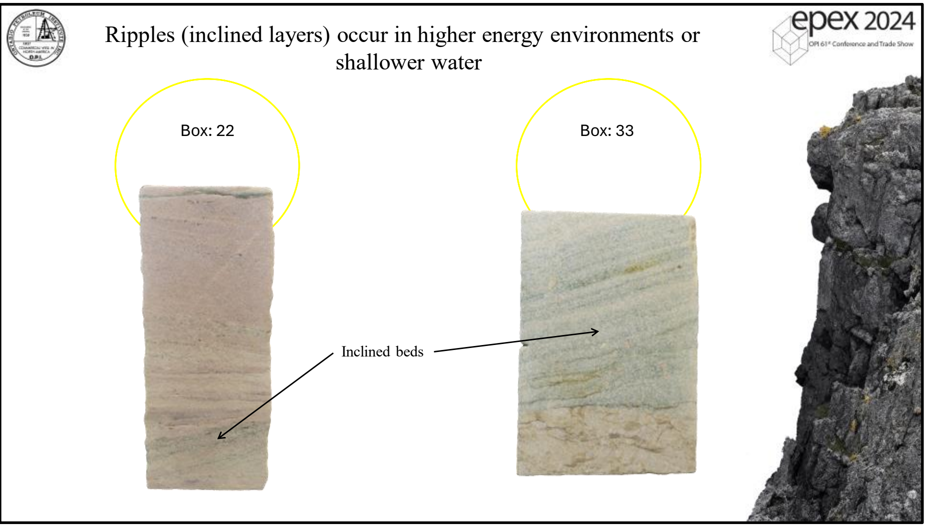
Slide 35: Eau Claire and Mount Simon units thicken into the Appalachian Basin and are water wet, thereby forming the deep saline aquifers of the Cambrian in SW Ontario.



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.

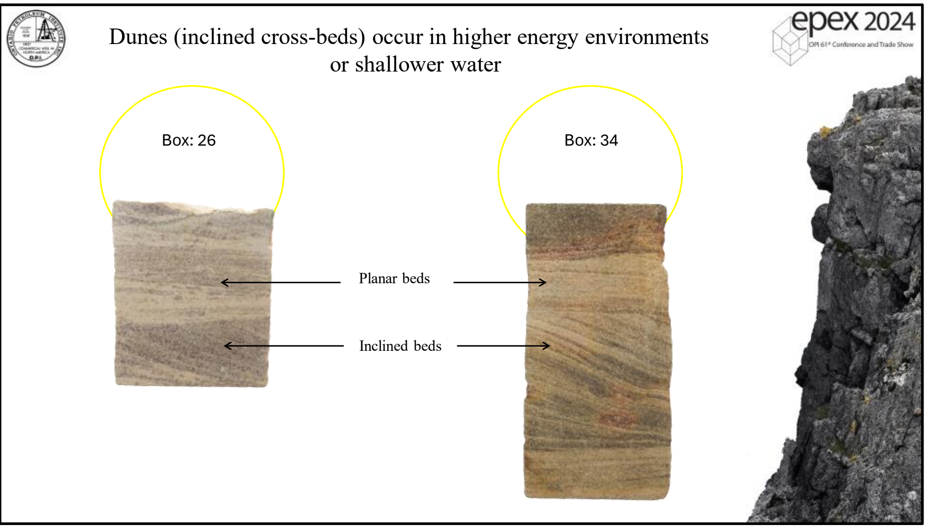


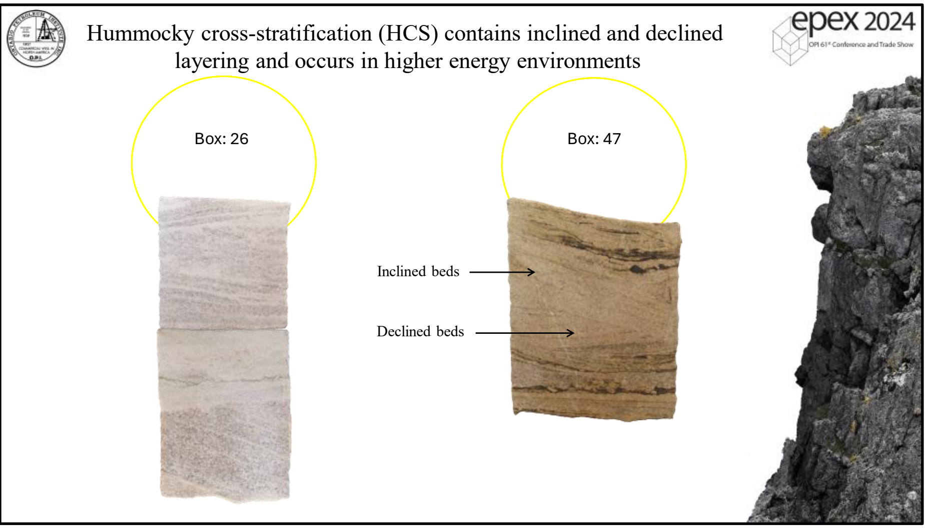
Slide 37: Planar beds or flat laminations that occur in lower energy or deeper water environments. Boxes 22, 32.



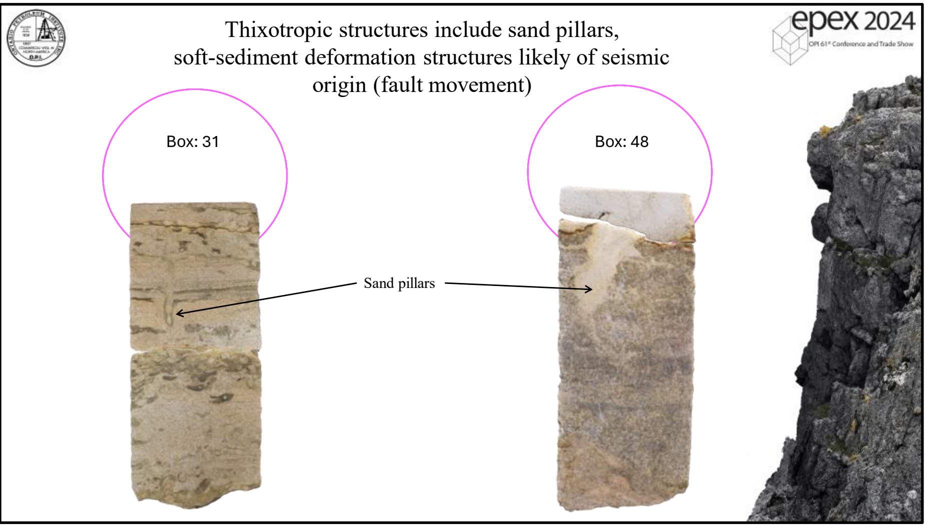
Slide 38: Ripples or inclined beds that occur in higher energy or shallow water environments. Boxes 22, 33.

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



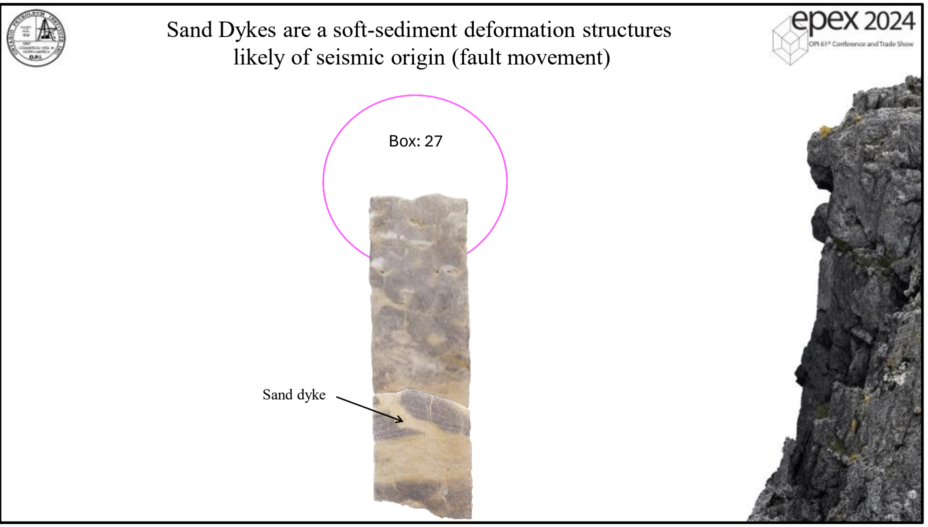


Slide 40: Hummocky cross-stratification (HCS) is identified by the presence of inclined and declined layering that sandwiches another layer, this typically occurs in very high energy depositional environments. Boxes 26, 47.

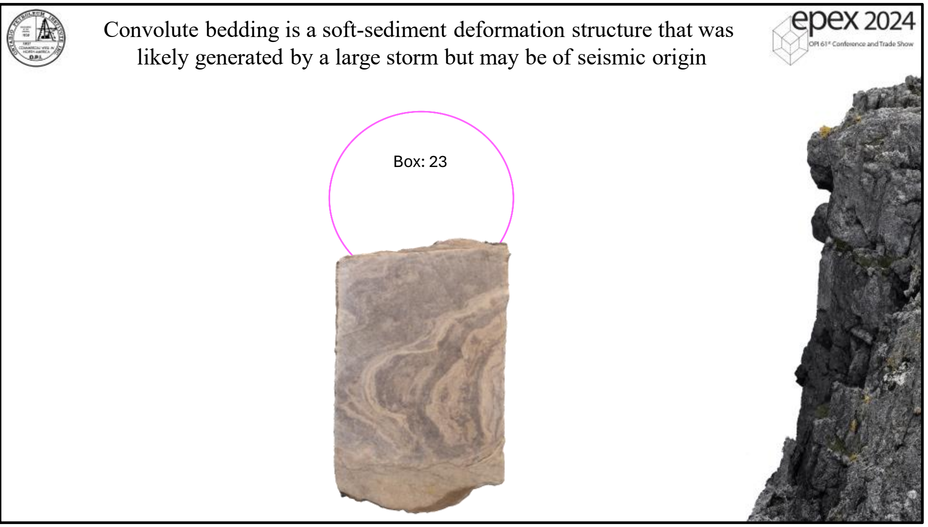


Slide 41: Thixotropic structures including sand pillars, sand dykes and convolute bedding, are examples of soft-sedimentary deformation structures, and many are likely of seismic origin during fault movements. In this slide we see sand pillars, a very small sand pillar structure on the left and a larger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

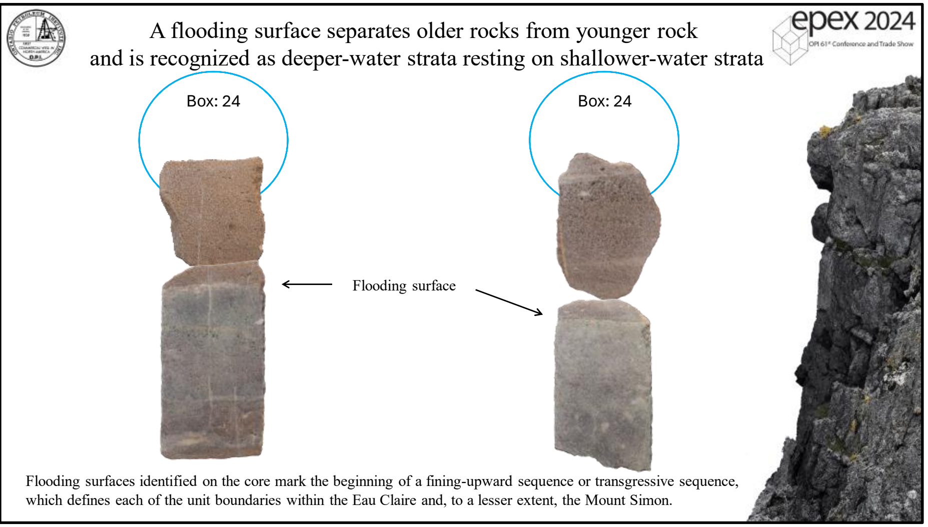
Slide 42: Here is an example of a sand dyke which is a classic soft-sediment deformation feature. Box 27.



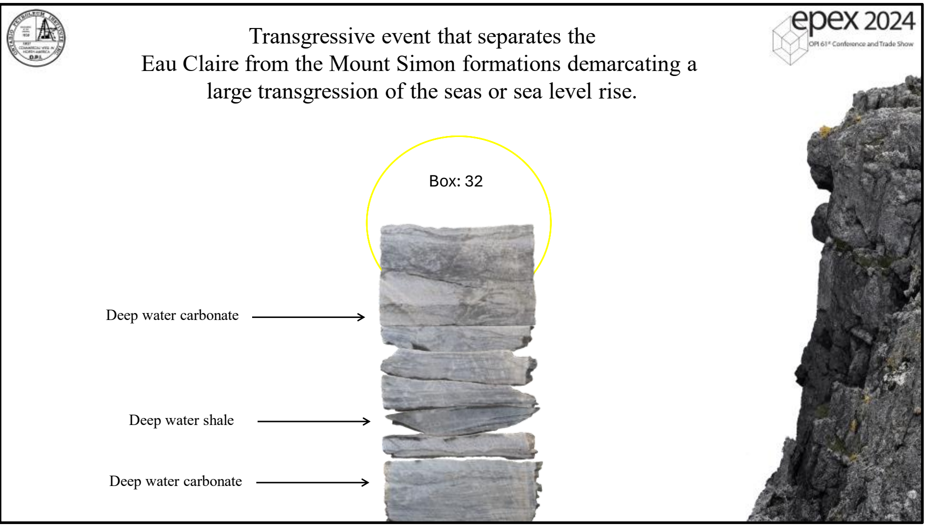
Slide 43: Here is an example of convolute bedding, another soft-sediment deformation structure. This feature may have formed following a large storm, algal mats became compressed into an accordion-like fashion and then turned onto their side. Box 23.



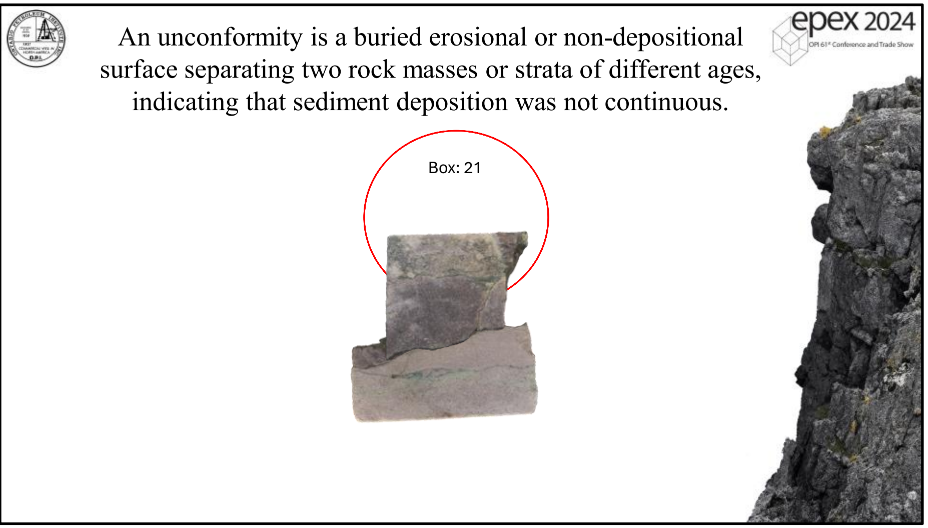
Slide 44: Flooding surface that marks the beginning of a fining upwards sequence or transgressive surface. The surface separates deeper water strata below, i.e., carbonates, from shallow water strata above, i.e., sandstones. Box 24.



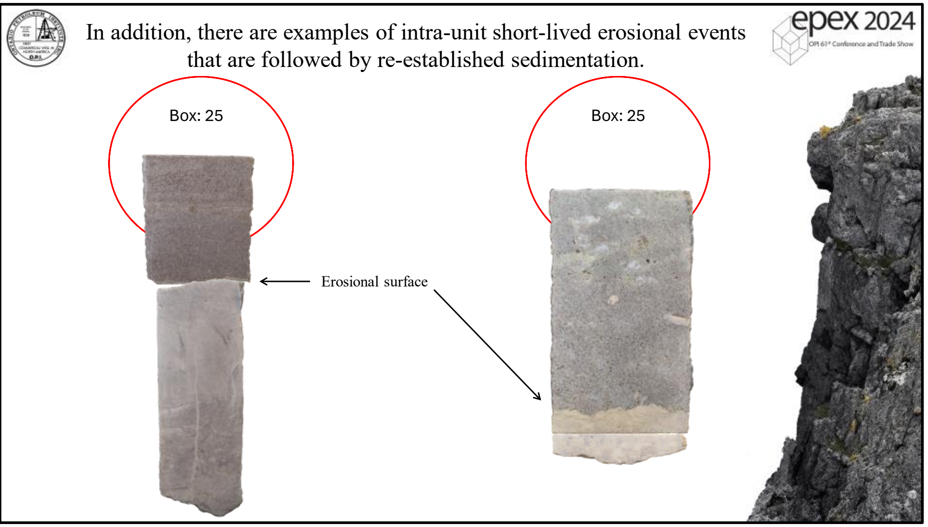
Slide 45: Transgressive event is recorded by the deposition of deeper water carbonates followed by a deep-water shale. This transgressive event separates the Mount Simon Formation below from the Eau Claire Formation above. Box 32.

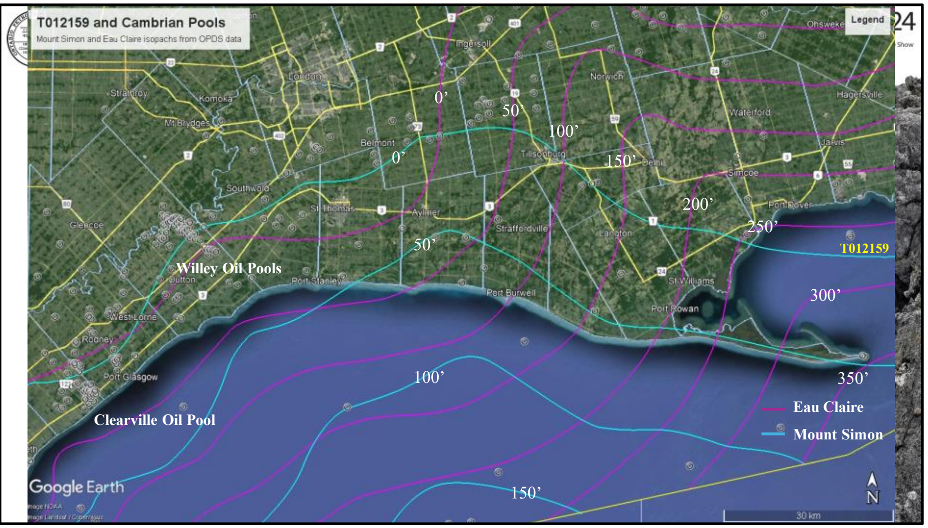


Slide 46: The unconformity that separates Cambrian sediments from the Middle Ordovician sediments. This is an erosional event that took place over a significant amount of time. Note the undulating surface between the layers. Box 21.



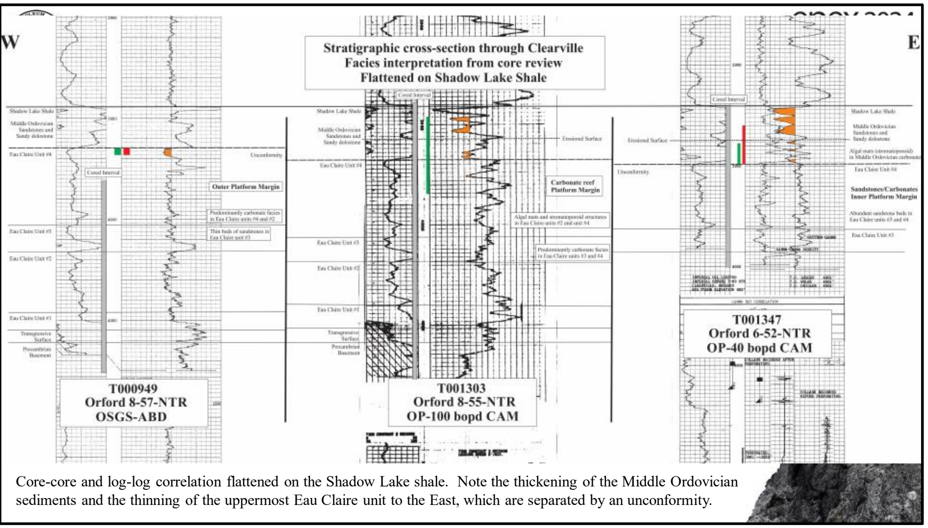
Slide 47: There are other short lived erosional events observed as irregular surfaces that separate different lithologies, here the carbonate rock at the bottom was eroded prior to deposition of the overlaying sand. Box 25.





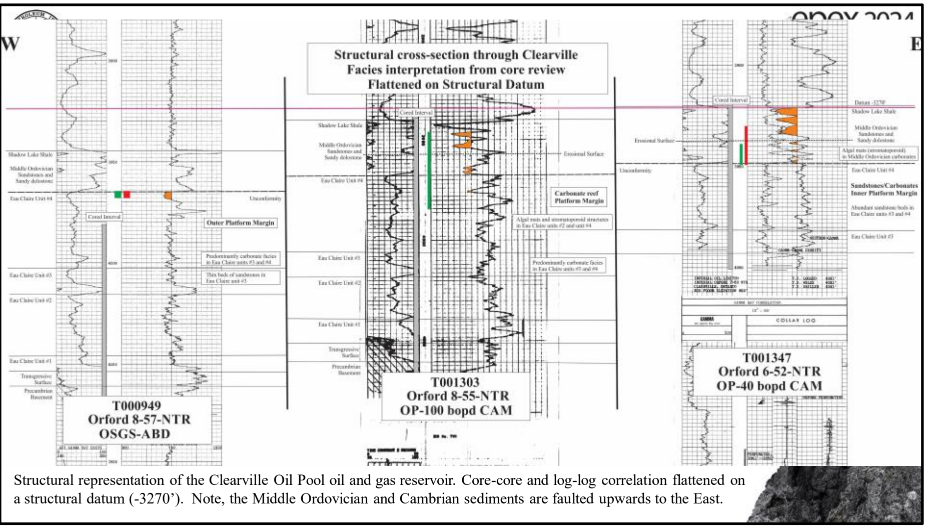
Slide 48: Isopach contours for the Eau Claire and Mount Simon formations generated using the geological data in OPDS. The isopach contours are labeled, along with the existing Cambrian-aged oil fields and the T012159 well. Thicker accumulations of Eau Claire, compared to Mount Simon, along the shoreline 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?



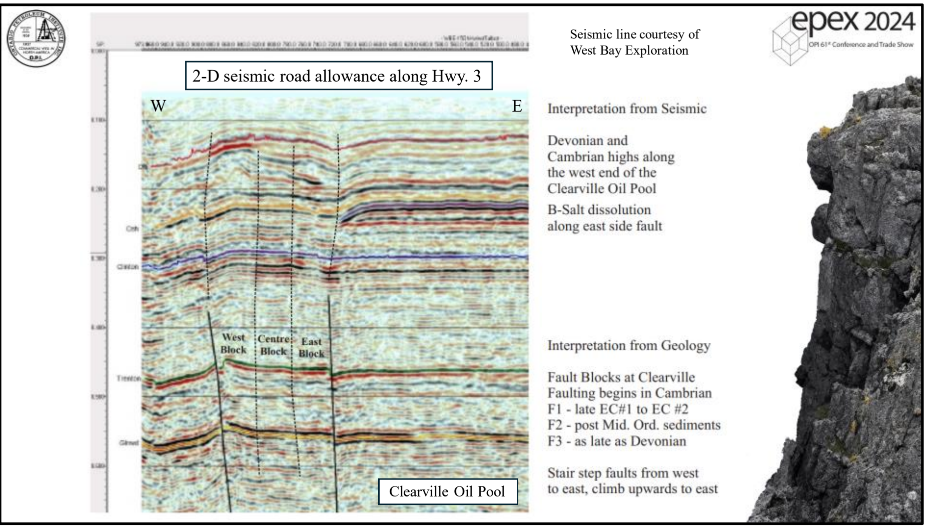
Core-core and log-log correlation flattened on the Shadow Lake shale. Note the thickening of the Middle Ordovician sediments and the thinning of the uppermost Eau Claire unit to the East, which are separated by an unconformity.

Slide 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.

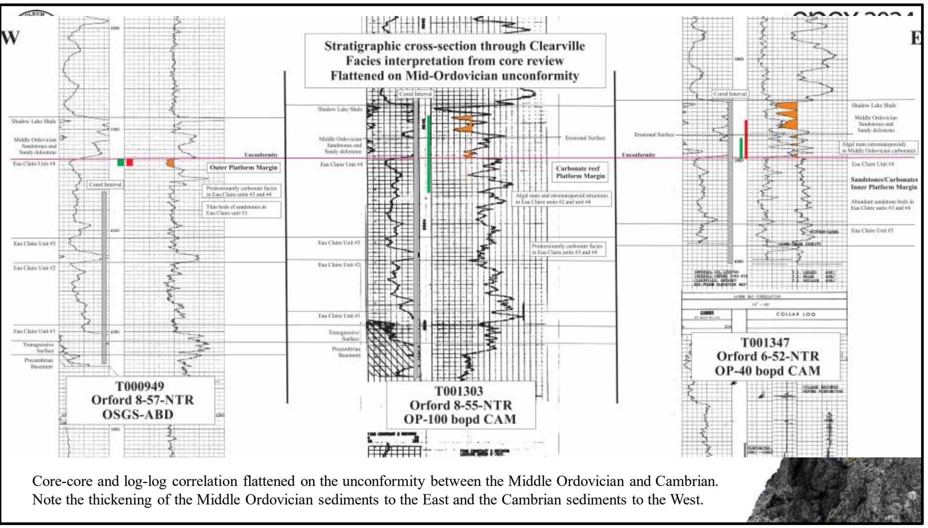


Structural representation of the Clearville Oil Pool oil and gas reservoir. Core-core and log-log correlation flattened on a structural datum (-3270'). Note, the Middle Ordovician and Cambrian sediments are faulted upwards to the East.

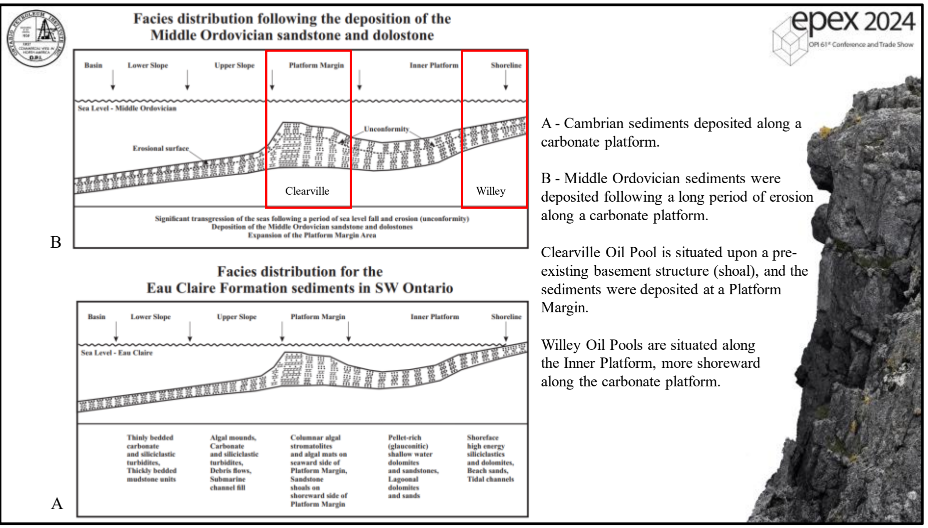
Slide 51: This is a structural cross-section hung on a structural datum. Note that the reservoir development is different on the West side of the pool compared to the Central and East side of the pool, which is the rationale for including faults between the wells on the cross-section. The sediments appear to be fault blocked up towards the East.



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.

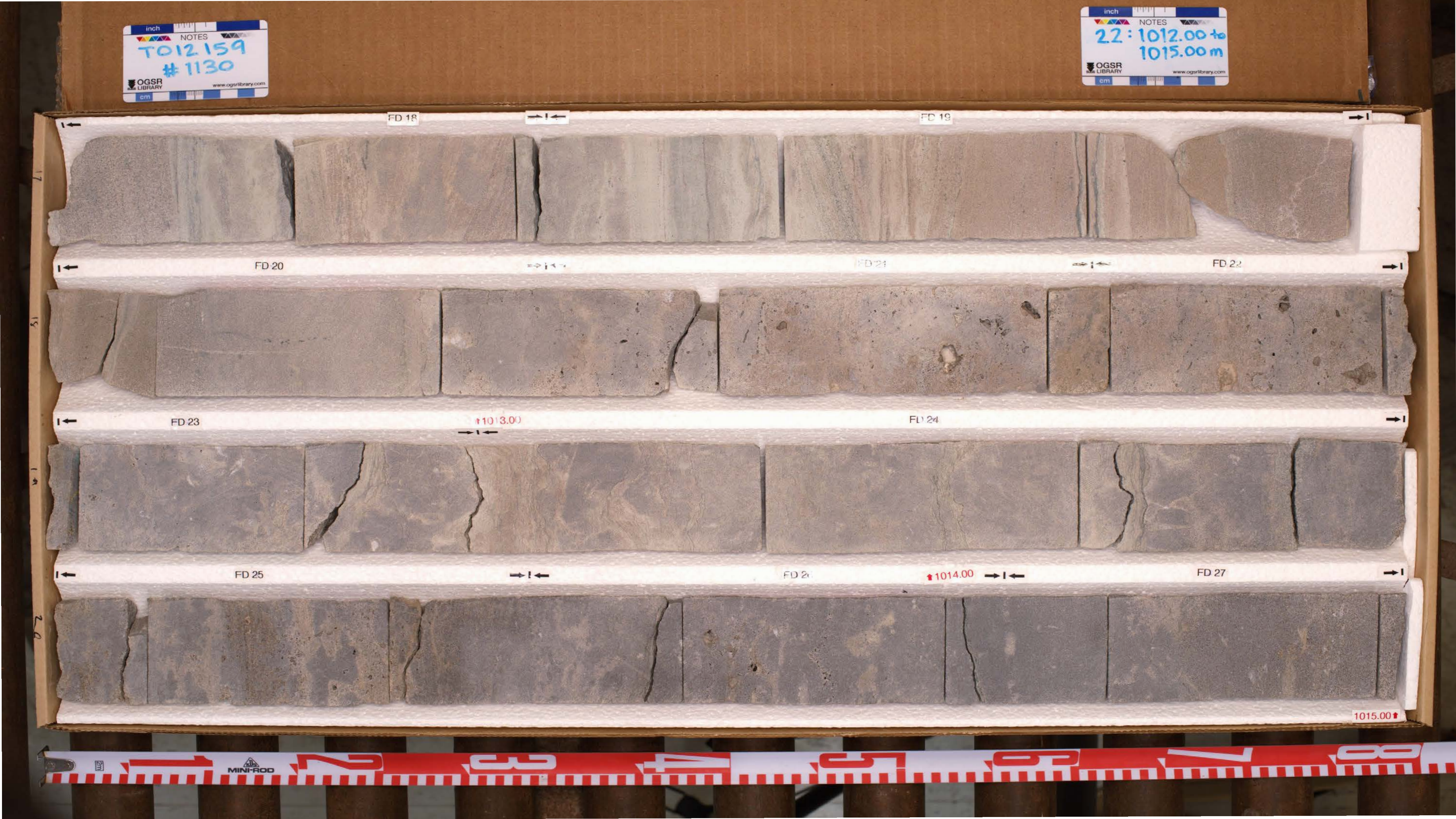


Slide 53: The best version of a stratigraphic cross-section across the Clearville Oil Pool is to hang the section on the unconformity between the Middle Ordovician and Cambrian sediments. It provides more insight into the geology at the time of deposition compared to the stratigraphic cross-section hung on the Shadow Lake shale. The Cambrian sediments thicken to the West and the Middle Ordovician sediments thicken to the East. This suggests that the Clearville structure tilted to the West during deposition of the Cambrian sediments, and then it tilted to the East during deposition of the Middle Ordovician sediments. The basin was active during these early days.



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.


T012159
#1130
21: 1009.00 to
1012.00 m
NOTES
OGSR LIBRARY
www.ogsrlibrary.com
FD 7
FD 8
FD 9
FD 10
FD 11
FD 12
1010.00
FD 13
FD 14
FD 15
FD 16
1011.00
FD 17
1012.00
MINI-ROD


T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
22: 1012.00 to
1015.00 m
FD 18
FD 19
FD 20
FD 21
FD 22
FD 23
1013.00
FD 24
FD 25
FD 26
1014.00
FD 27
1015.00
MINI-ROD


inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
inch
NOTES
23: 1015.00 to
1018.00 m
OGSR LIBRARY
www.ogsrlibrary.com
cm
FD 28
FD 29
FD 30
FD 31
FD 32
FD 33
1016.00
FD 34
FD 35
SP 36
SP 37
1017.00 NOT ANALIZED
1018.00m
MINI-ROD
1
2
3
4
5
6
7
8

inch
NOTES
TO12159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
24: 1018.00 to
1020.98m
FD38
FD39
FD40
1018.00m
FD41
FD42
FD43
FD44
1019.00
FD45
FD46
FD47
FD48
1020.00
MINI-ROD


inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
inch
NOTES
25: 1020.98 to
1023.99 m
OGSR LIBRARY
www.ogsrlibrary.com
cm
FD49
FD50
1021.00
FD51
FD52
FD53
FD54
1022.00
FD55
FD56
FD57
1023.00
FD58
2m
MINI-ROD
1
2
3
4
5
6
7
8


inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
26: 1023.99 to
1026.99 m
FD59
FD60
FD61
1024.00
FD62
FD64
FD65
1025.00
FD66
FD67
FD68
1026.00
FD70
FD71
MINI-ROD

T012159
#1130
27: 1026.99 to
1029.99 m
OGSR LIBRARY
www.ogsrlibrary.com
FD72
FD73
FD74
1027.00
FD75
FD76
FD77
1028.00
FD78
FD79
1029.00
FD80
MINI-ROD

T012159
#1130
28: 1029.99 to
1031.95 m
FD81
SP82
NOT ANALYZED
1030.00
NOT ANALYZED
SP83
FD84
FD85
1031.00
SP86
1031.95m
MINI-ROD

T012159
#1130
29 : 1034.70 to
1037.72 m
NOTES
OGSR LIBRARY
www.ogsrlibrary.com
FD 87
FD 88
1034.70m
1035.00
FD 90
FD 91
1036.00
FD 93
FD 94
FD 96
1037.00
MINI-ROD


inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
30: 1037.72 to 1040.74 m
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
MINI-ROD

T012159
#1130
31: 1040.74 to 1043.44 m
NOTES
OGSR LIBRARY
www.ogsrlibrary.com
FD 108
FD 109
FD 110
FD 111
FD 112
FD 113
FD 114
FD 115
1042.00
FD 116
FD117
FD118
1043.00
MINI-ROD

T012159
#1130
32: 1043.44 to 1045.88 m
OGSR LIBRARY
www.ogsrlibrary.com
FD119
FD120
FD121
1044.00
FD122
FD123
FD124
1045.00
FD125
MINI-ROD

T012159
#1130
NOTES
OGSR LIBRARY
www.ogsrlibrary.com
33: 1045.88 to 1048.22 m
FD126
FD127
FD128
1046.00
FD129
FD130
FD131
1047.00
FD132
FD133
1048.00
MINI-ROD


TO12159
#1130
34: 1048.22 to
1050.20 m
FD134
FD135
FD136
FD137
1049.00
FD139
FD140
FD141
1050.00
1050.20m
MINI-ROD

T012159
1130
35: 1050.30 to
1053.33 m
OGSR LIBRARY
www.ogsrlibrary.com
FD142
FD143
1050.30M
FD144
FD145
FD146
1051.00
FD147
FD148
FD149
FD150
1052.00
FD151
FD152
1053.00
MINI-ROD


inch
NOTES
T012159
#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
MINI-ROD


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
FD166
1057.00
FD167
MINI-ROD


T012159
#1130
38: 1057.43 to
1060.93 m
OGSR LIBRARY
www.ogsrlibrary.com
FD168
FD170
1058.00
FD 172
FD 173
1059.00
FD 174
FD 175
FD 176
FD 177
1060.00
FD 178
MINI-ROD

inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
39: 1060.93 to 1063.20 m
FD 179
FD 180
1061.00
FD 181
FD 182
FD 183
FD 184
1062.00
FD 185
1063.00
MINI-ROD


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
MINI-ROD
1
2
3
4
5
6
7
8

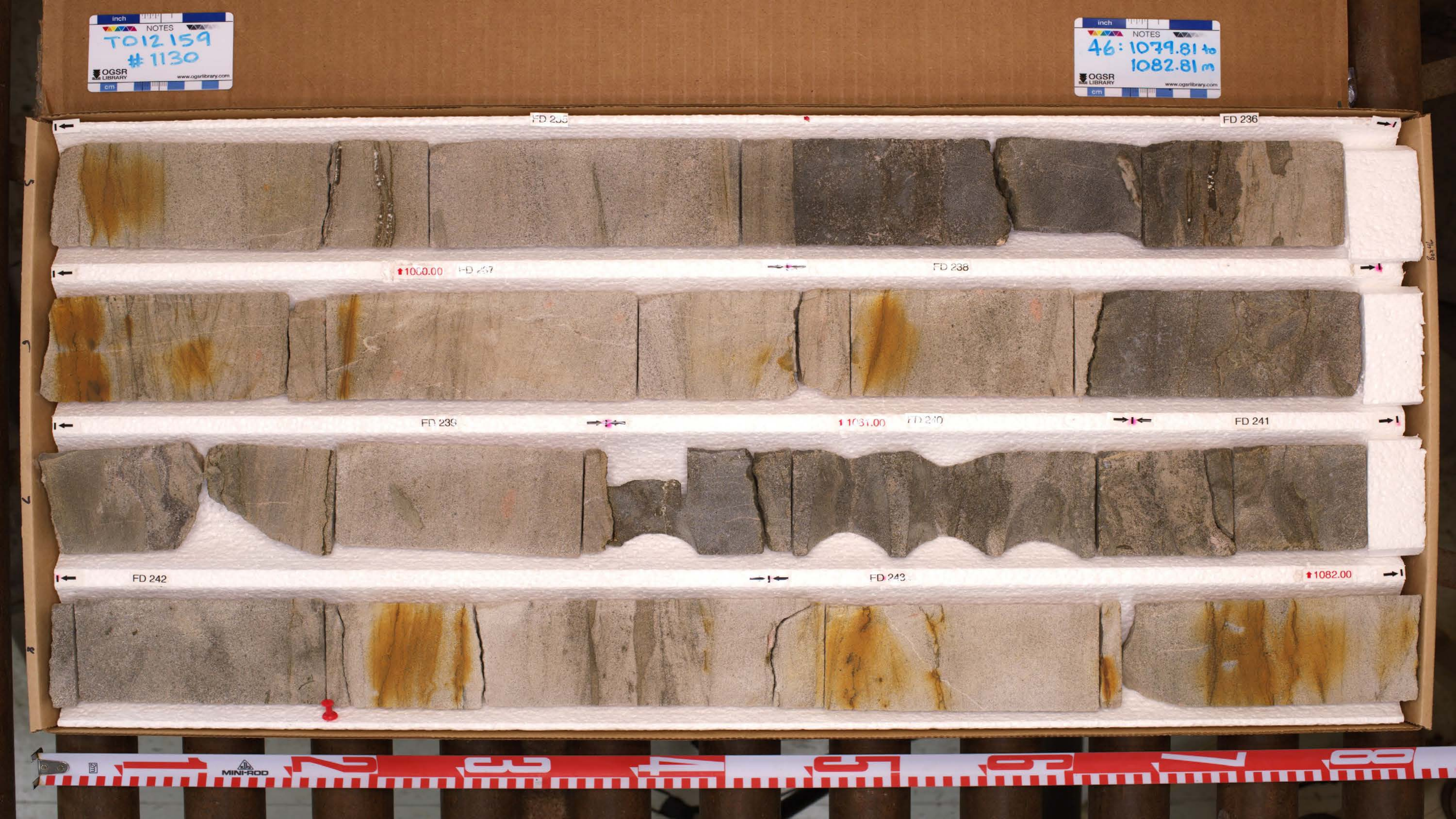

T012159
#1130
41: 1065.51 to 1067.75 m
OGSR LIBRARY
www.ogsrlibrary.com
NOTES
FD 193
FD 194
FD 195
FD 196
1066.00
FD 197
FD 198
FD 199
FD 200
1067.00
1067.75M
MINI-ROD

inch
NOTES
TO12159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
42: 1067.80 to 1070.11 m
FD201
FD202
1067.80m
FD203
1068.00
FD204
FD205
FD206
FD207
1069.00
FD208
FD209
1070.00
MINI-ROD

inch
NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
inch
NOTES
43:1070.11 to
1072.38 m
OGSR LIBRARY
www.ogsrlibrary.com
cm
FD210
FD211
FD212
FD213
1071.00
FD214
FD215
FD216
1072.00
MINI-ROD

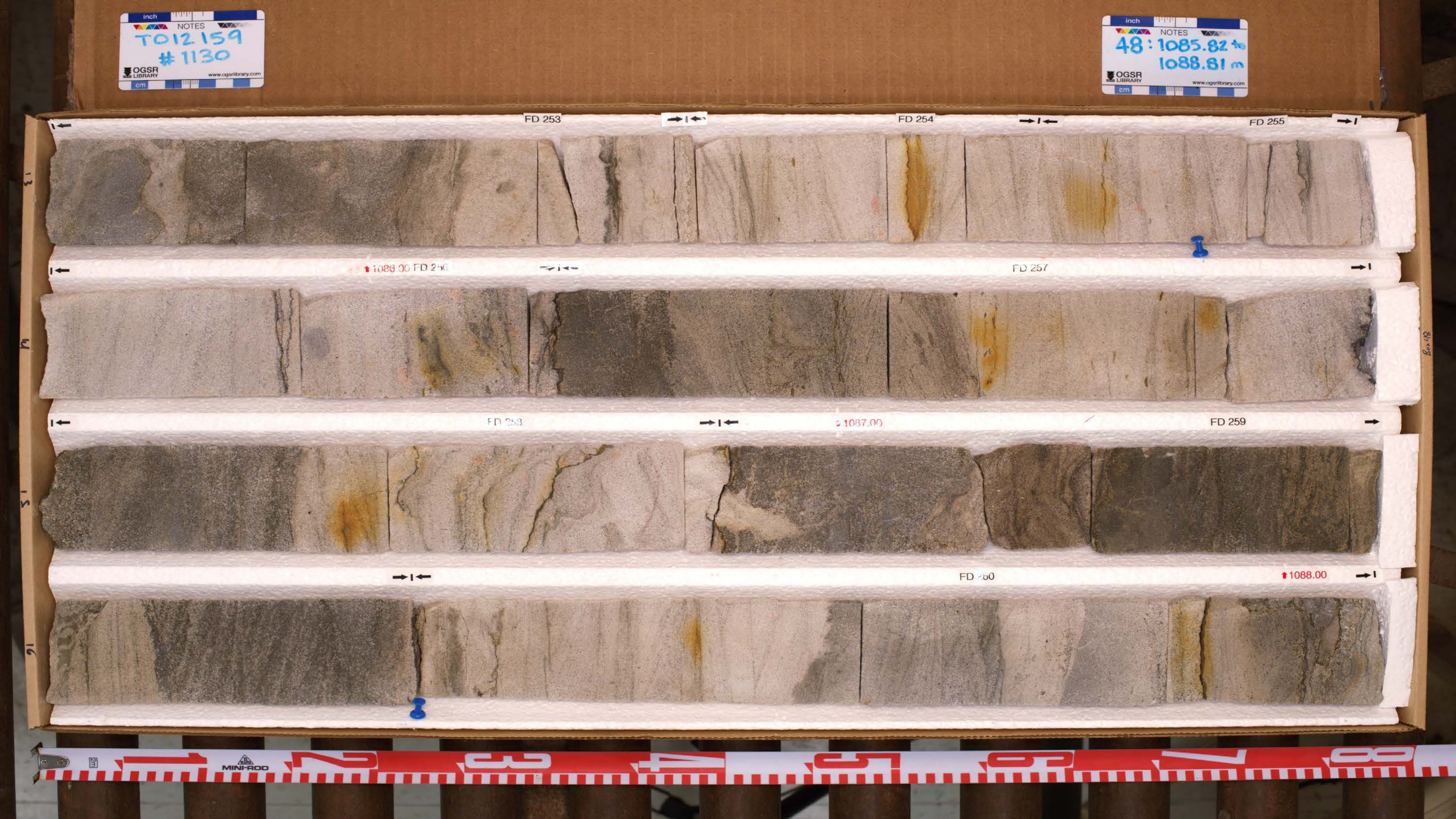

inch
NOTES
TO12159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
inch
NOTES
44: 1072.38 to
1074.70m
OGSR LIBRARY
www.ogsrlibrary.com
cm
FD217
FD218
FD219
FD220
FD221
SP222
1073.00
SP223
FDA224
NOT ANALYZED
1074.00
1074.70m
MINI-ROD


NOTES
T012159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
NOTES
45: 1076.80 to
1079.81 m
OGSR LIBRARY
www.ogsrlibrary.com
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



inch
NOTES
TO12159
#1130
OGSR LIBRARY
www.ogsrlibrary.com
cm
46: 1079.81 to
1082.81 m
FD 236
1080.00
FD 238
FD 239
1081.00
FD 241
FD 242
FD 243
1082.00
MINI-ROD


inch
NOTES
T012159
#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
084.00
FD 250
FD 251
FD 252
1085.00
MINI-ROD


T012159
#1130
48 : 1085.82 to
1088.81 m
NOTES
OGSR LIBRARY
www.ogsrlibrary.com
FD 253
FD 254
FD 255
1086.00 FD 256
FD 257
FD 258
1087.00
FD 259
FD 260
1088.00
MINI-ROD