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Fluid Electrical Conductivity Logging in Borehole DGR-1 at the Bruce Site, Tiverton, Ontario, Canada

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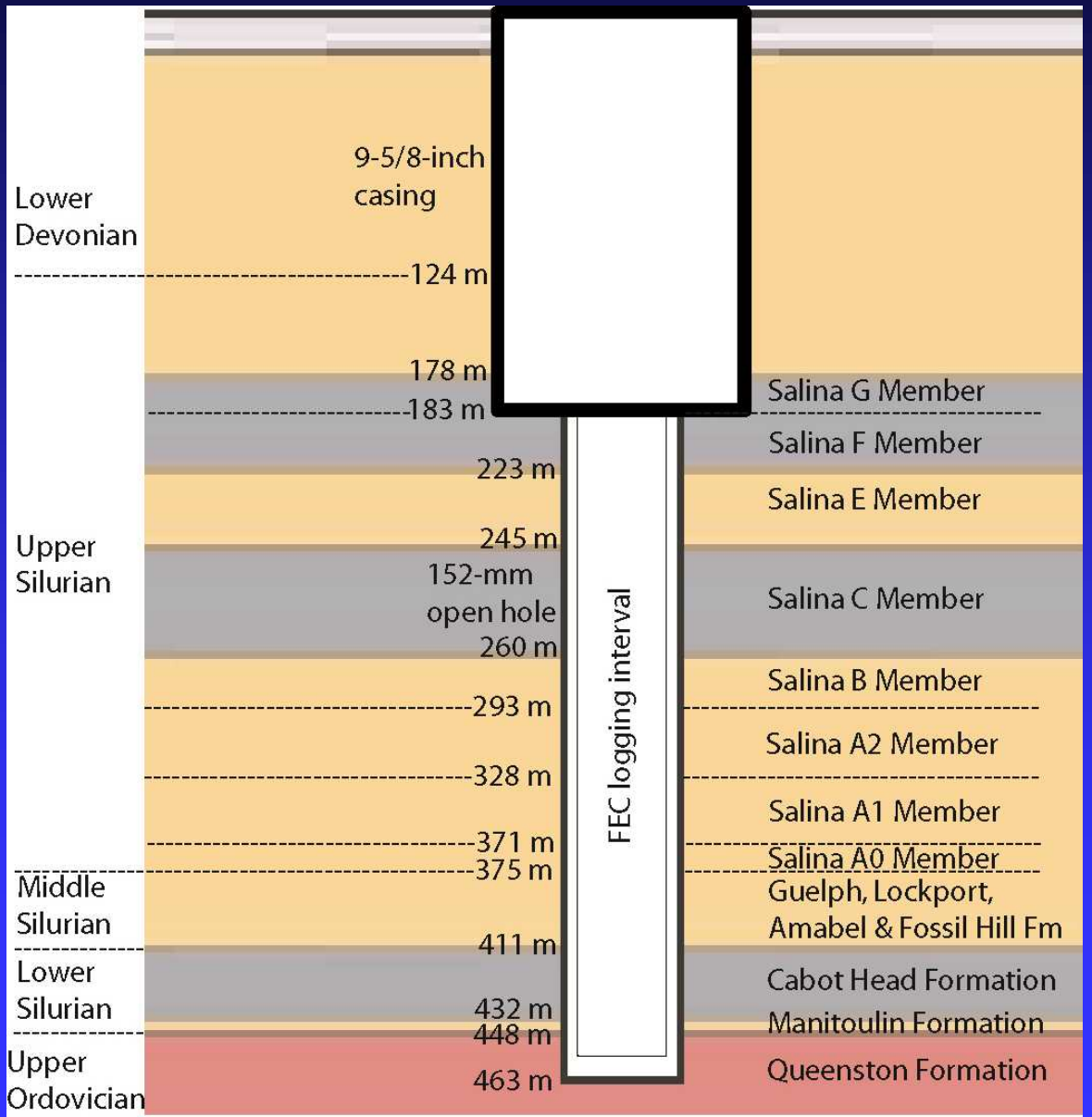
Introduction

- FEC logging entails replacing the fluid in a borehole with another fluid having an electrical conductivity that contrasts with that of the fluids in the formation(s) penetrated by the borehole
- After fluid replacement has been completed, repeated logging runs are conducted over the length of the water column with an electrical conductivity probe to identify locations where the FEC of the water column is changing
- The locations where the FEC changes represent places where water is either flowing into or out of the borehole
- FEC logging was performed in DGR-1 at the Bruce site to identify the intervals within each of the Silurian formations and members that provide the most flow so that those intervals could then be isolated for straddle-packer testing

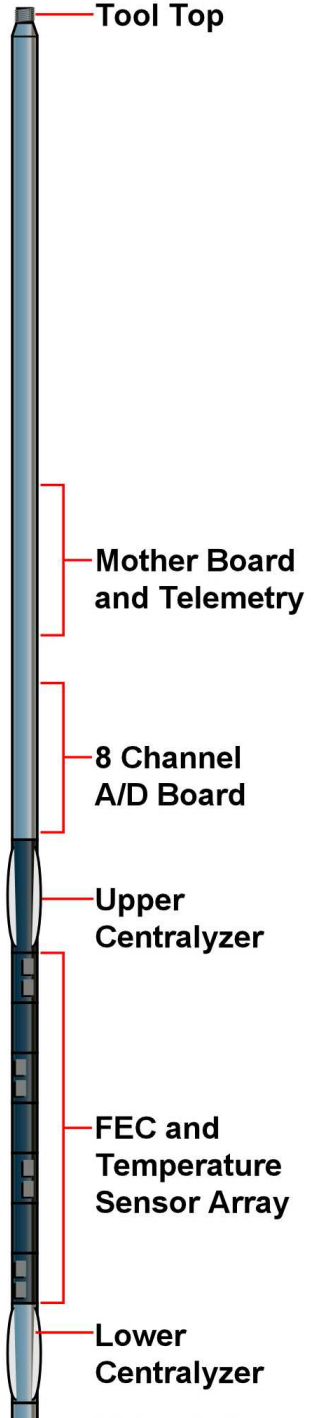
Location of the Bruce Site

Stratigraphy at DGR-1



FEC Logging

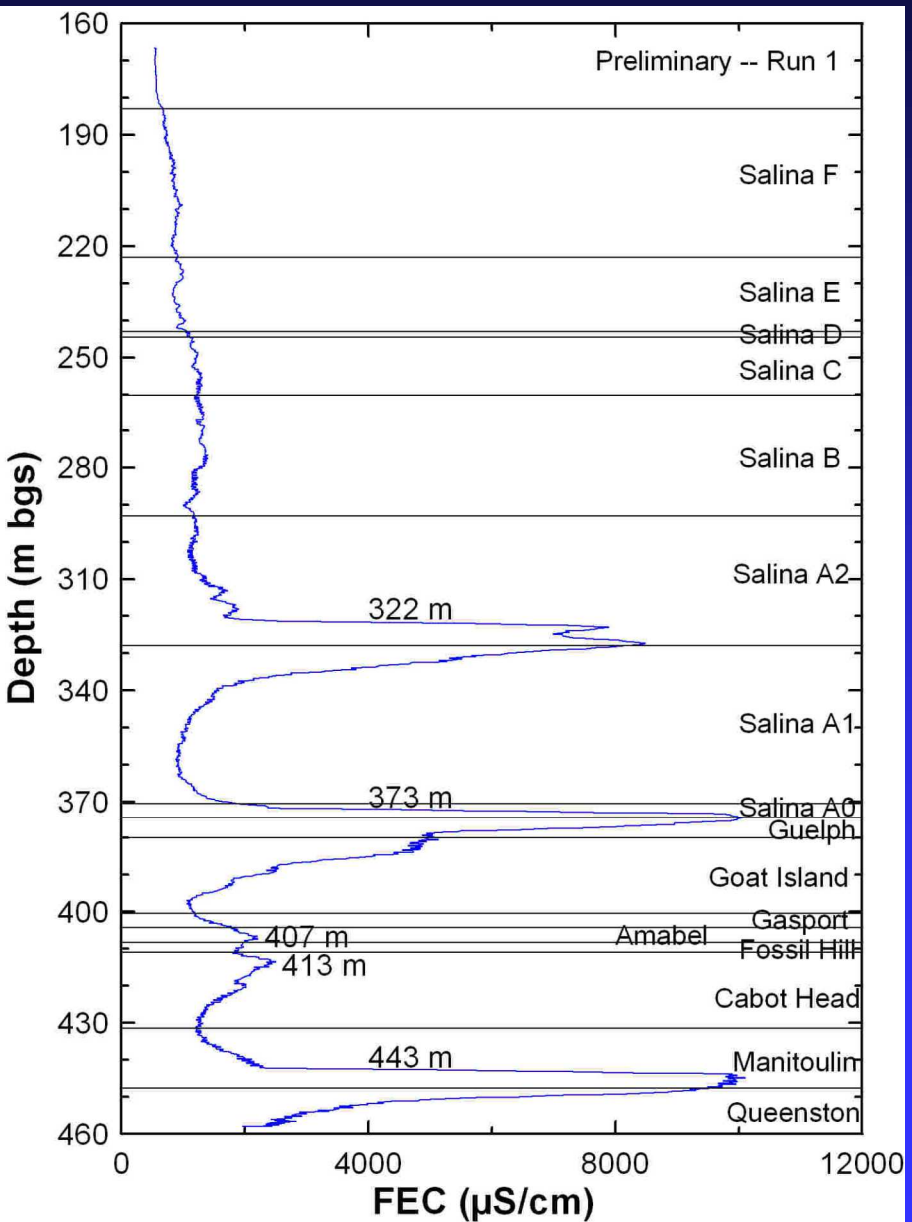
- The borehole was flushed with Lake Huron water until FEC stabilized at approximately 500 µS/cm
- The hydraulic head in the Silurian formations, combined with the low density of the Lake Huron water compared to that of the natural fluids in the Silurian formations, caused DGR-1 to be in a flowing artesian condition after fluid replacement
- Three logging runs were performed at ~75-minute intervals, with the first run starting ~90 minutes after fluid emplacement



FEC Logging Tool

- four separate sensors for the measurement of FEC and temperature
- sensors are spread at 15.24-cm separations along the length of the tool and rotated 90° from one another
- FEC measured with six-pole type sensors, and temperature is measured with thermistors
- fully digital telemetry with all analog-to-digital conversion performed downhole
- maximum FEC = 20,000 µS/cm

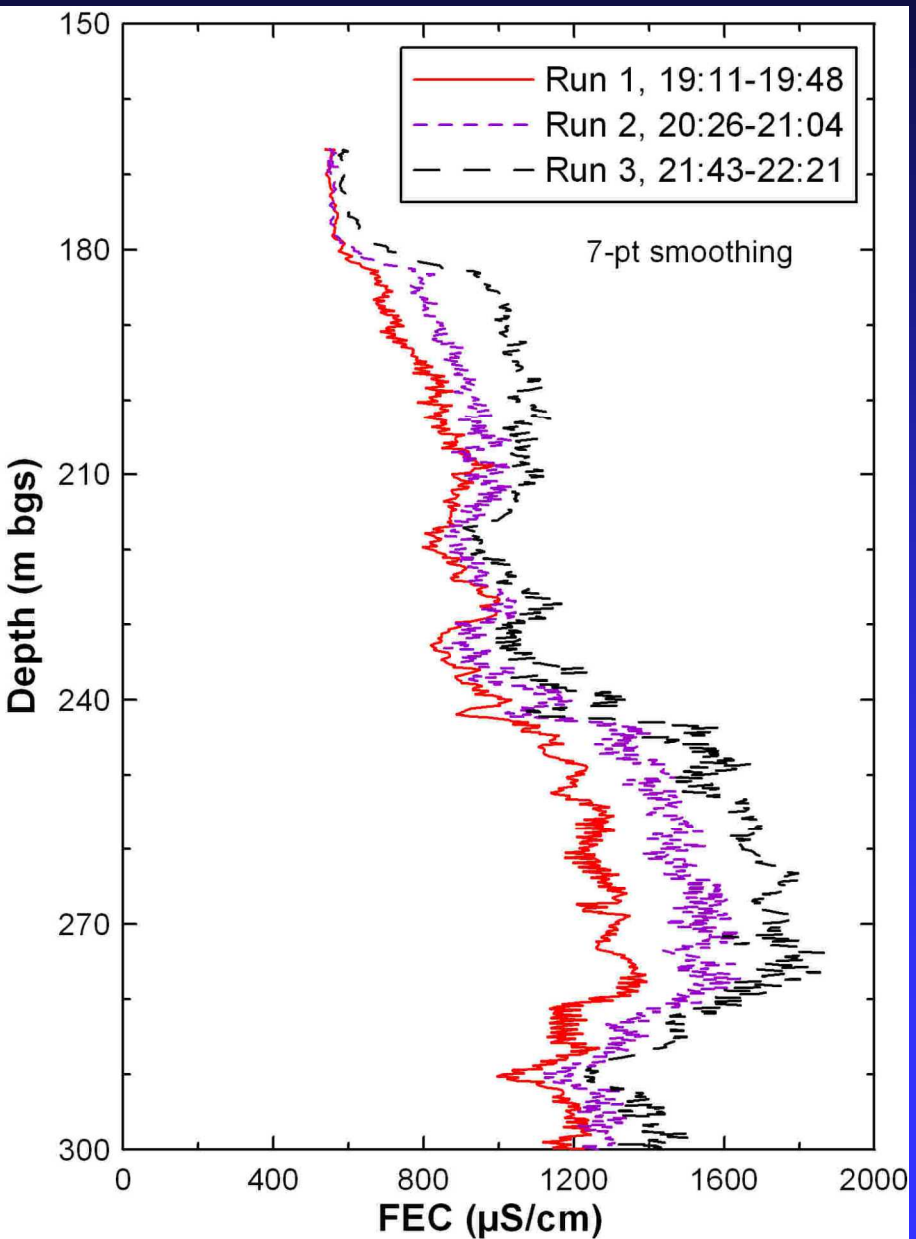
FEC Logging Results



An FEC spike can represent:

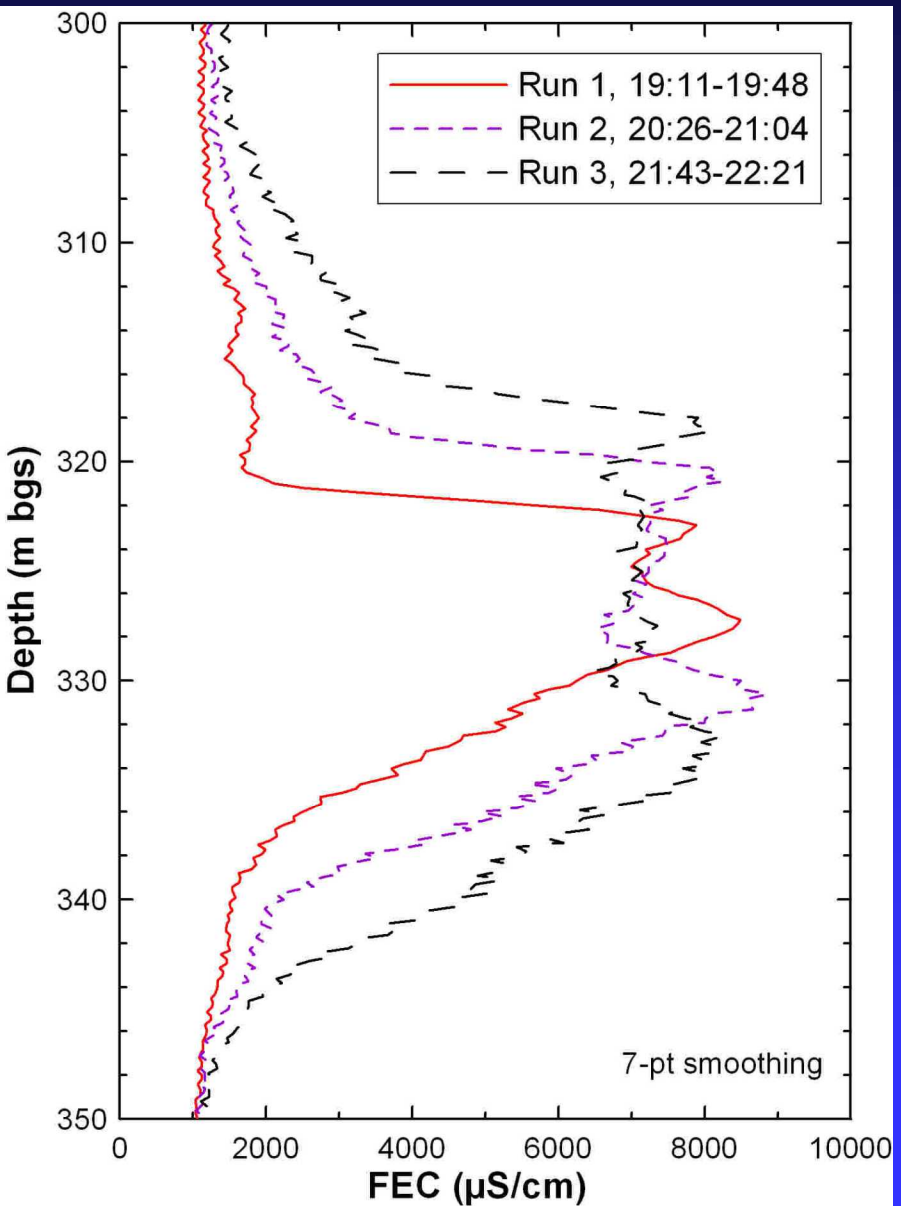
- high inflow (reflecting high K and/or a high gradient)
- high salinity
- or both

Time Evolution of FEC Profile



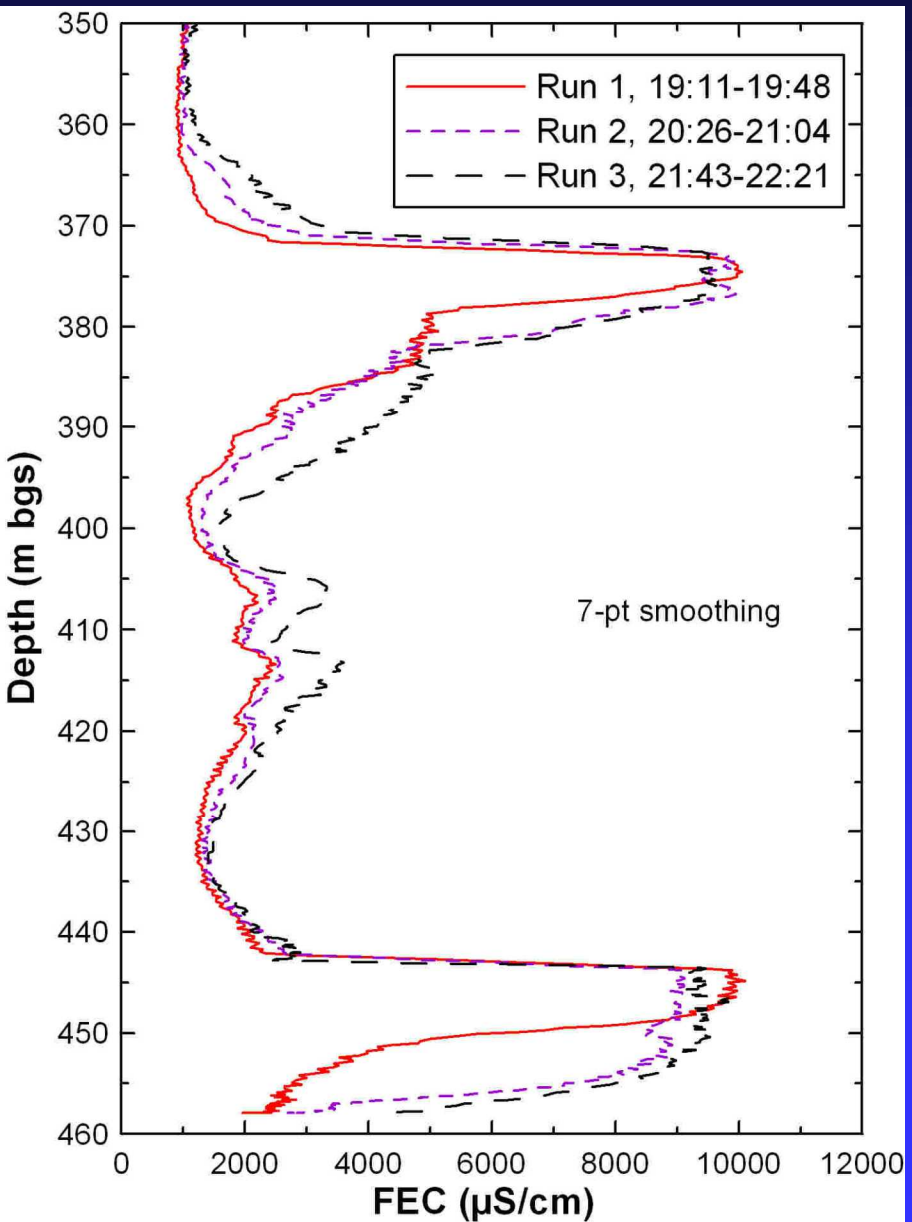
No pronounced inflow zones were observed down to 300 m, although some zones (e.g., ~245-275 m) showed more increase in FEC with time than other zones (e.g., ~210-230 m)

Time Evolution (2)



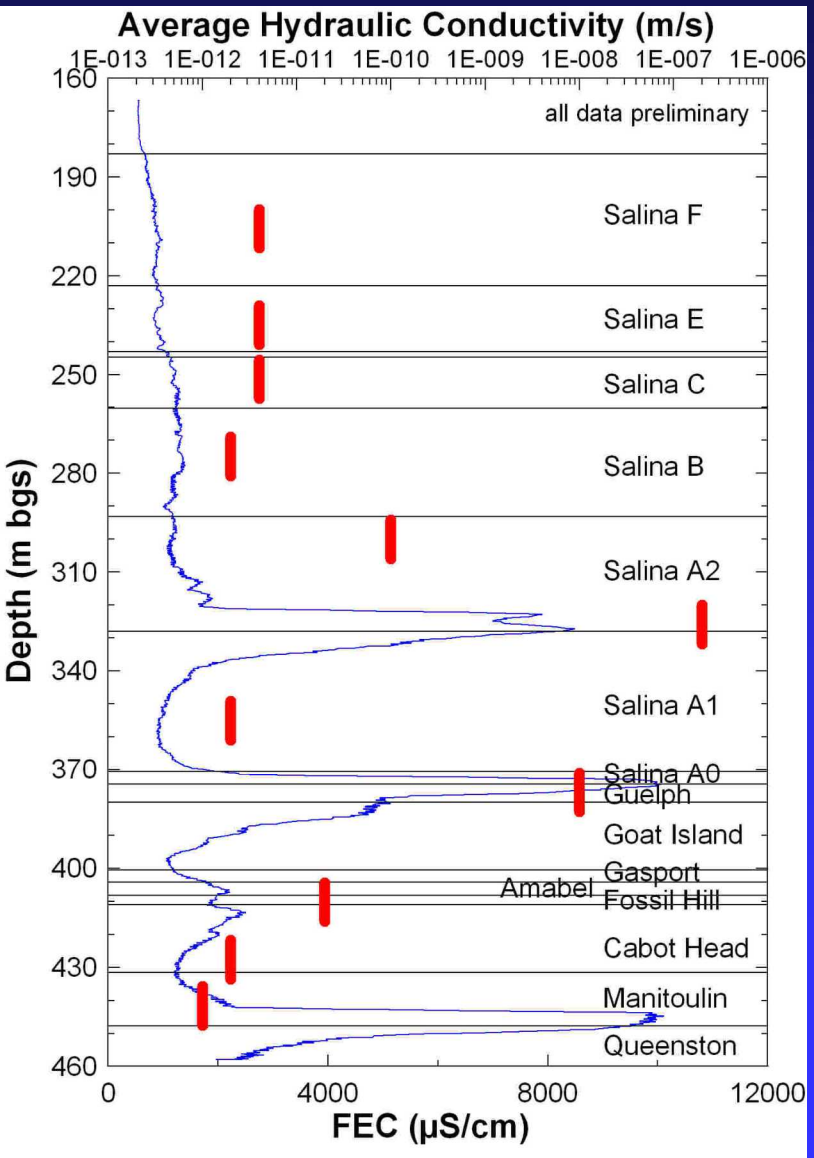
The FEC spike at ~322 m (lower A2 Member of Salina Formation) spread both upward and downward with time, probably reflecting both upward flow and sinking of dense fluid

Time Evolution (3)



The FEC spikes at ~373 m (A0 Member of Salina Formation) and ~443 m (lower Manitoulin Formation) moved only downward, reflecting sinking of dense fluid

Comparison of FEC Log and Straddle-Packer Hydraulic Testing Results



- Two of the three horizons showing the largest FEC spikes also had high hydraulic conductivities
- The FEC spike at the lower Manitoulin probably represents highly saline fluid rather than high hydraulic conductivity
- One zone of moderate K was not identified by the FEC logging – may have been identified by inducing a higher gradient

Summary and Conclusions

- Three sets of downward and upward FEC logs were run in DGR-1, identifying three major and two minor discrete inflow zones in the borehole
- Water entering the hole at the upper major inflow zone from approximately 322 to 330 m bgs appears to be moving both upward and downward in the hole
- Water entering at the other inflow zones appears to be moving primarily downward, probably because it has a higher density than the Lake Huron water in the hole

Summary and Conclusions (2)

- Comparison of the average K values inferred from the hydraulic tests with the FEC data shows that the FEC logging clearly identified the zones of highest hydraulic conductivity in the borehole
- Hydraulic conductivity does not correlate perfectly with the magnitude of FEC because the FEC of the formation water entering the hole at one depth is not necessarily the same as that of the water from another formation entering at a different depth
- The majority of the borehole that showed little increase in FEC with time appears to have an average $K < 10^{-11}$ m/s