Infill Drilling Optimization – Impact on Well Performance, Spacing and Recovery Factors; Learnings From The Cardium Formation

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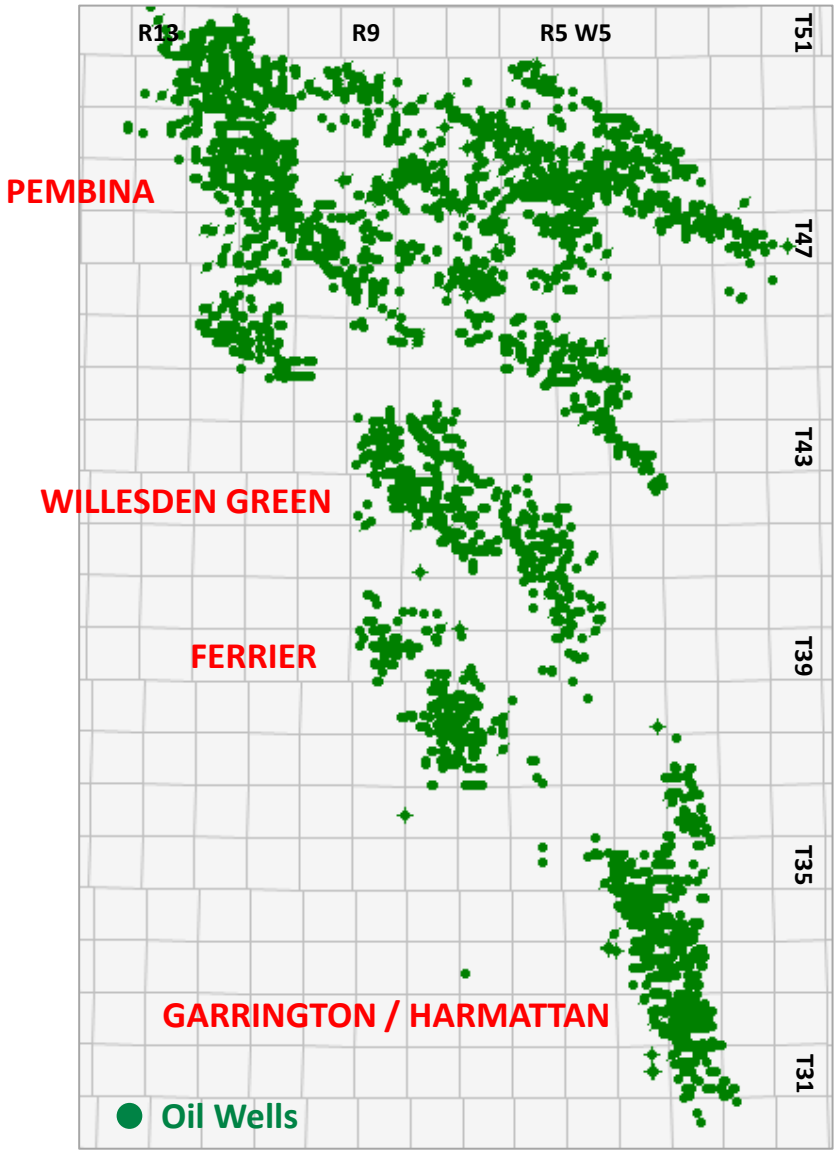
Presentation Outline

- Problem Statement
- Analysis Methodology
- The Cardium Formation – Geology
- Infill Drilling Optimization
  - Well Performance
  - Recovery Factors
- Reservoir Modelling
  - When “Enough is Enough”
- Conclusions

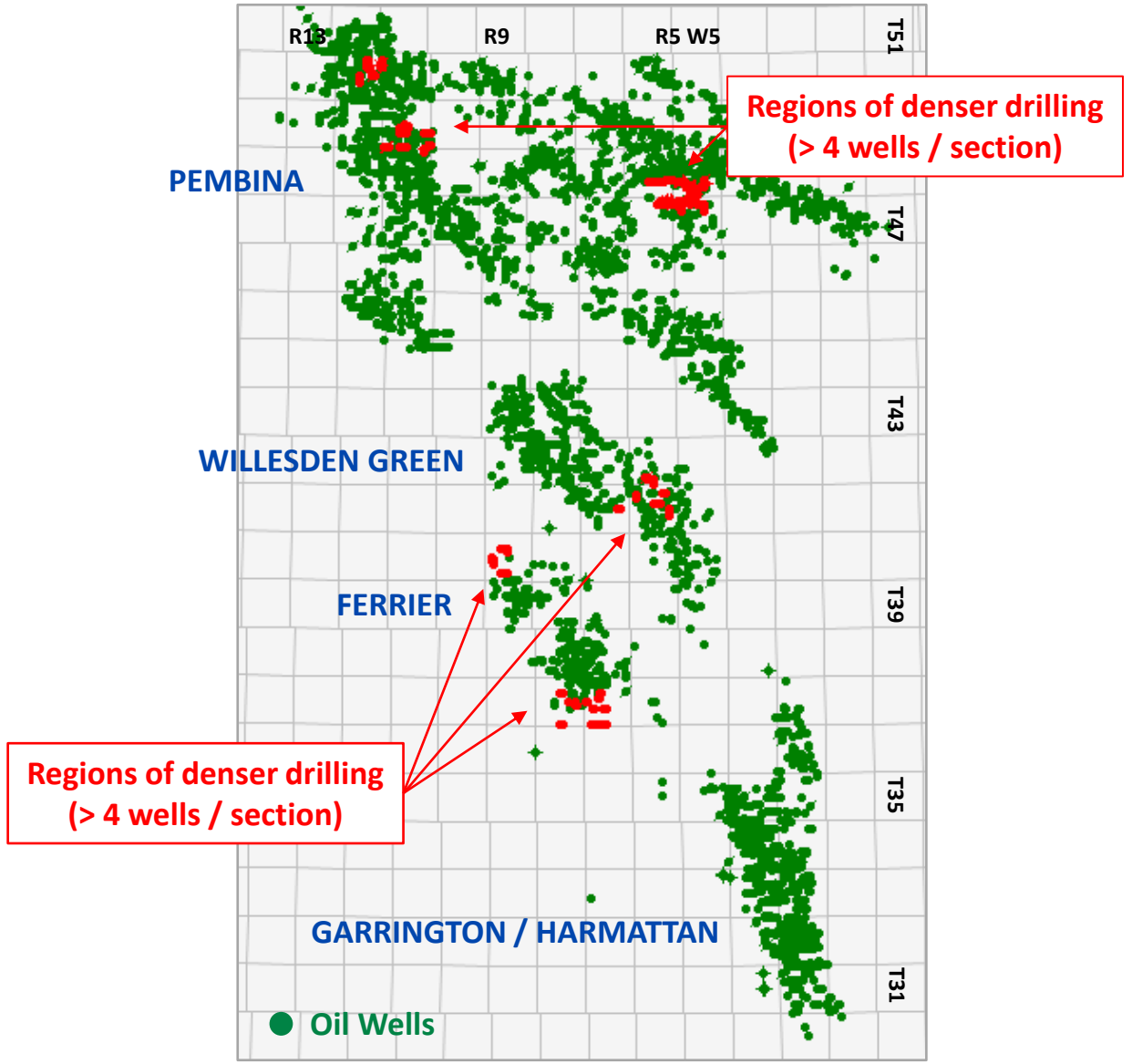
Problem Statement

- Numerous operators have been developing the Cardium formation in West-Central Alberta from Pembina to Harmattan areas.
- The development strategy employed is exclusively through horizontal wells with multi-staged hydraulic fracturing.
- Variable well densities of 4 to 8 wells per section (256 hectares) have been utilized.
- What is the impact on well performance of these varying well densities?
- Is *"more the merrier"* or is the *"law of diminishing returns"* affecting well performance?
- What reservoir characteristics are driving increased well density and higher recovery factors?

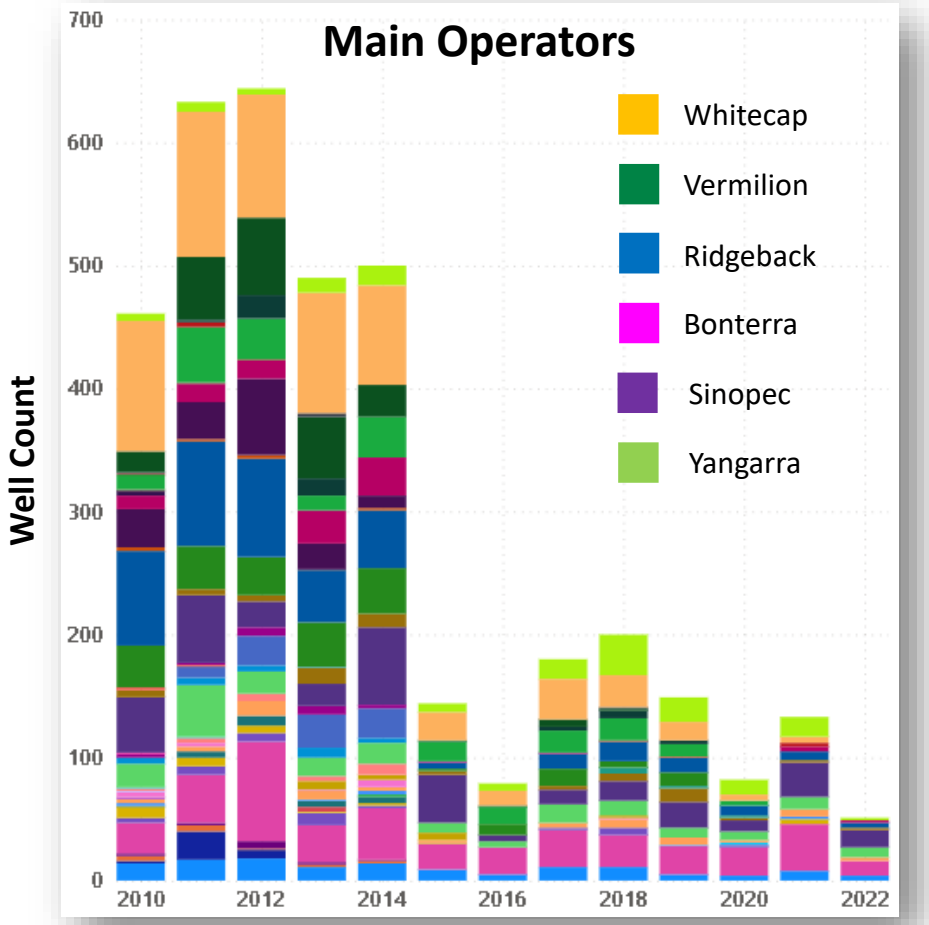


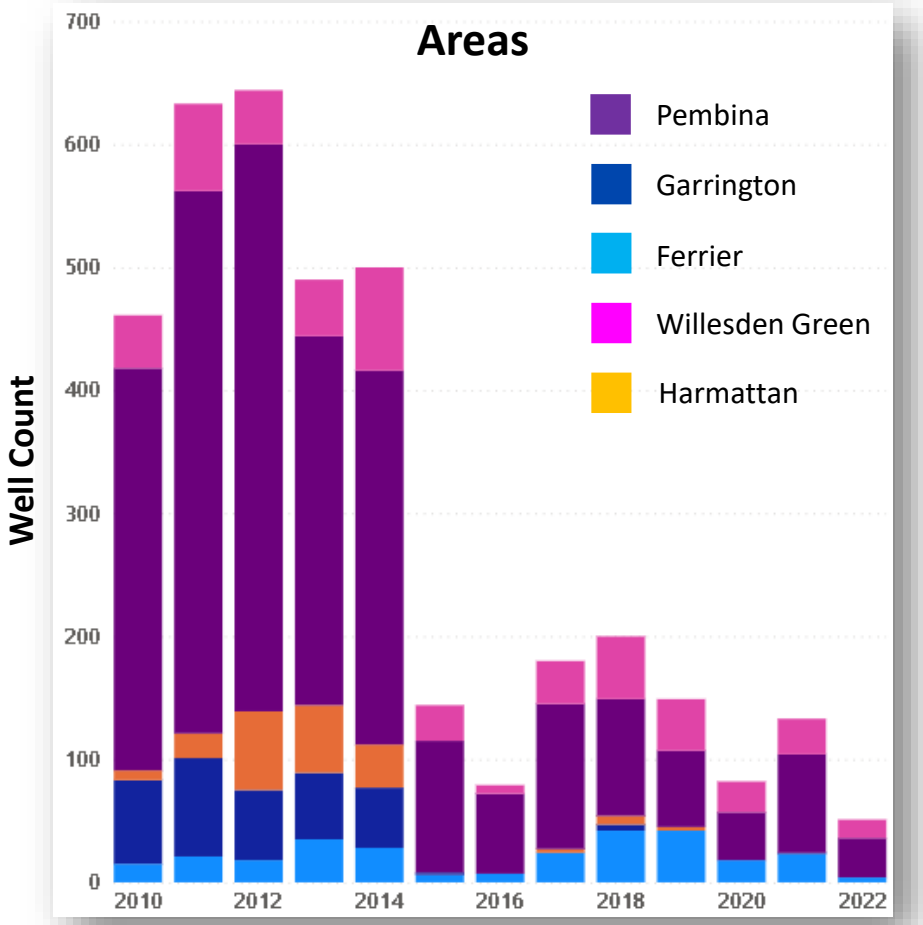
Analysis Methodology

- The pre-dominant drilling density employed by operators is 4 wells per section (400 m spacing).
- Focus on areas where, higher density (6 or 8 wells per section) has been employed by various operators.
- Evaluate well performance, recovery factors and parent-child interactions.
- Understand local geology and reservoir quality drivers for higher well density.

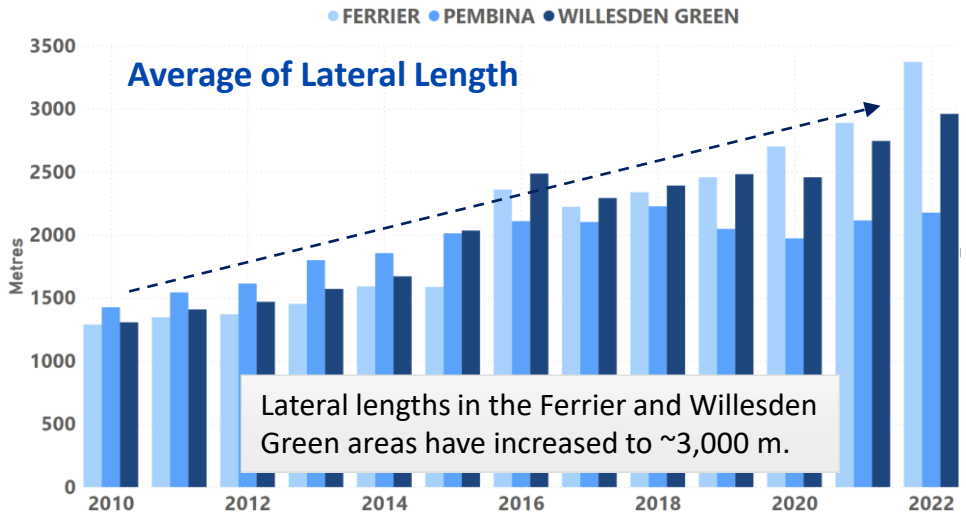


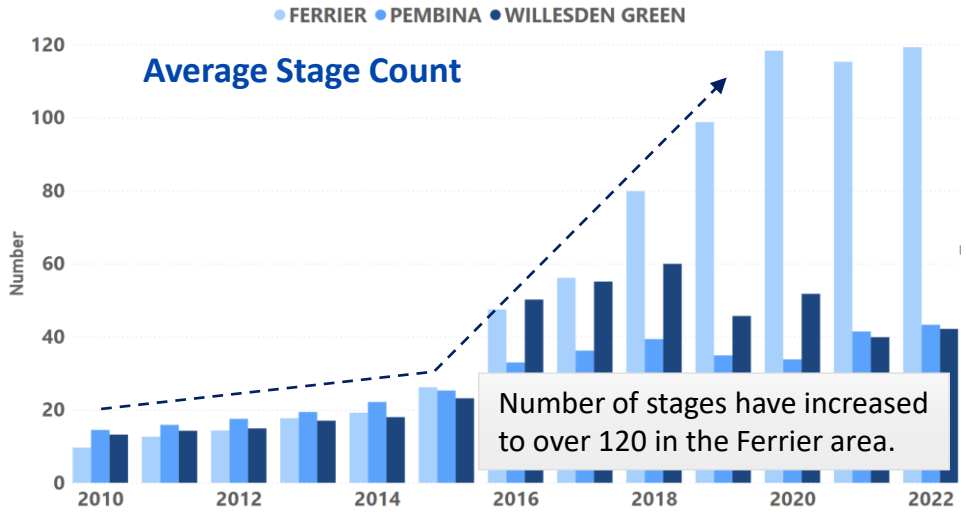
The Cardium Development – From Pembina to Harmattan

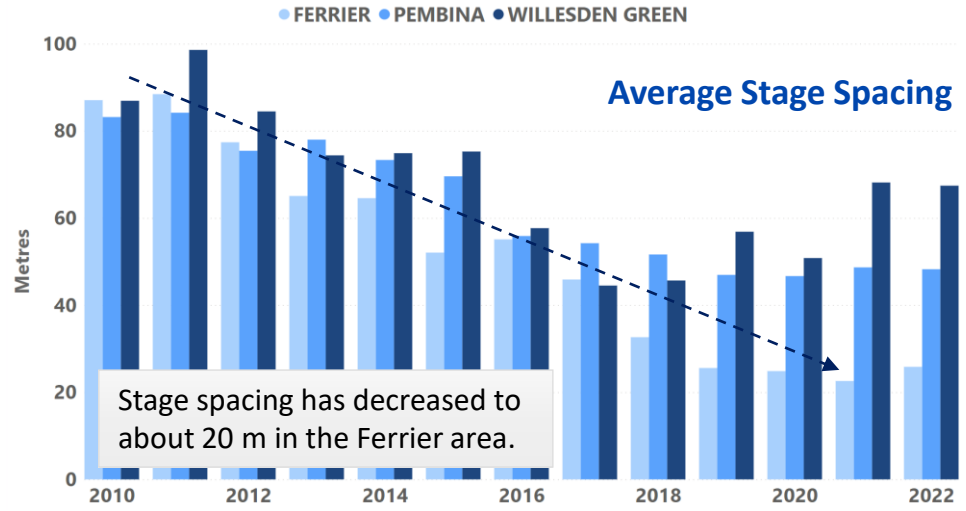


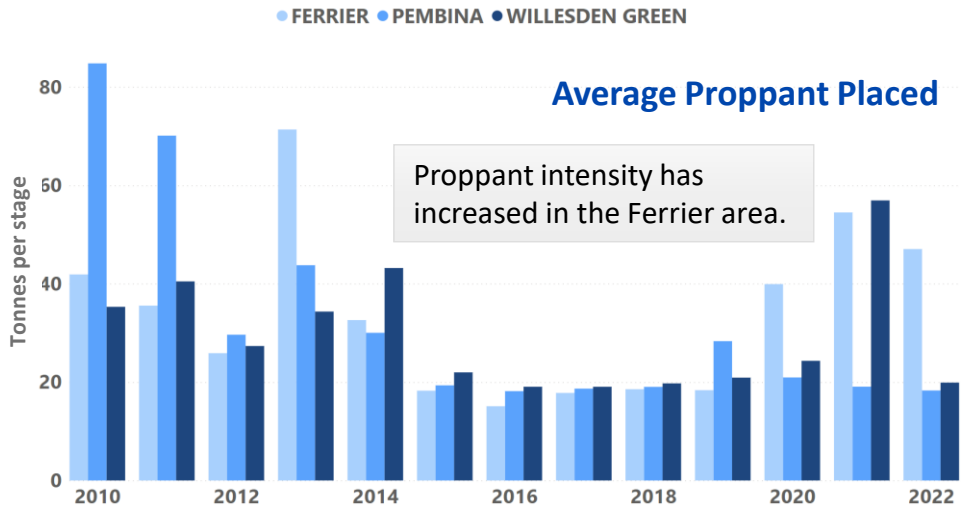


The Cardium Development – Average D & C Parameters



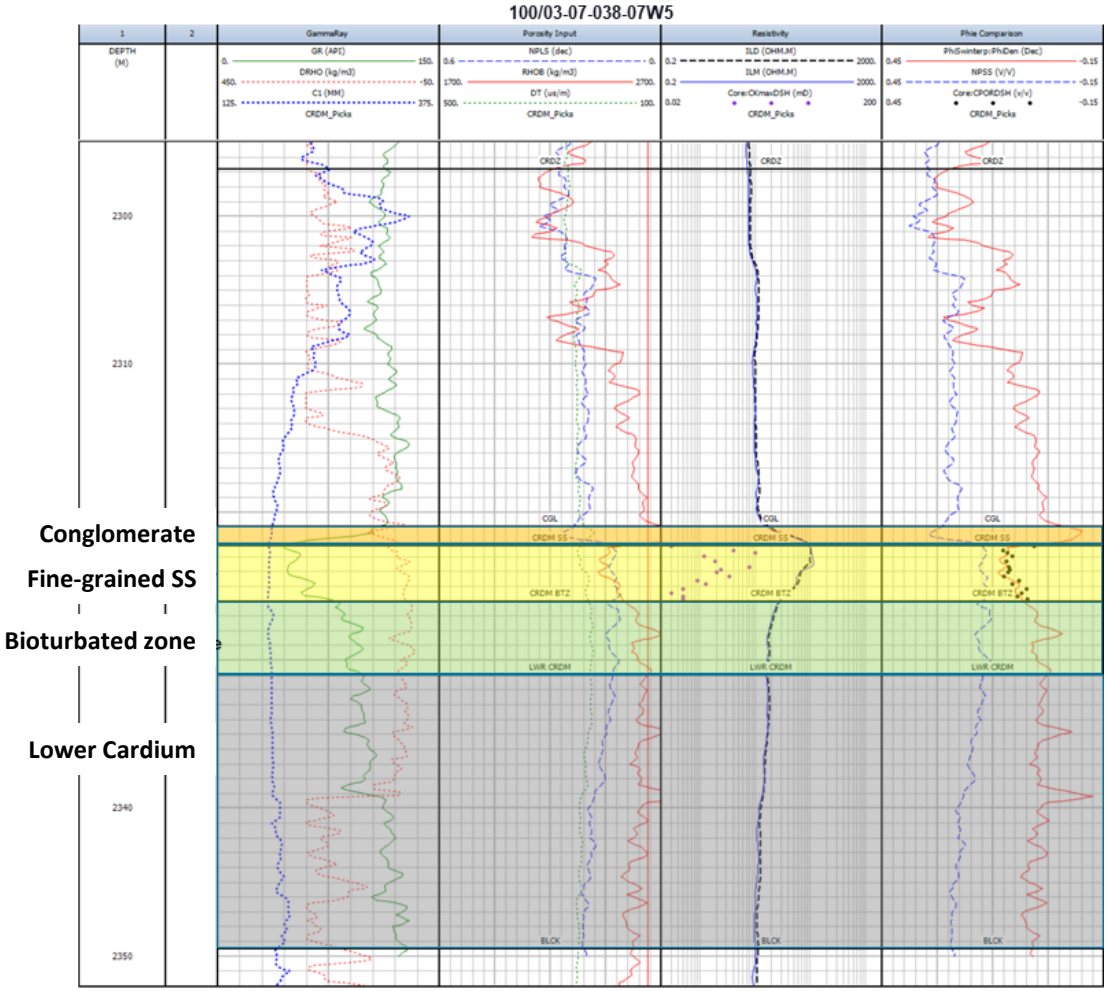




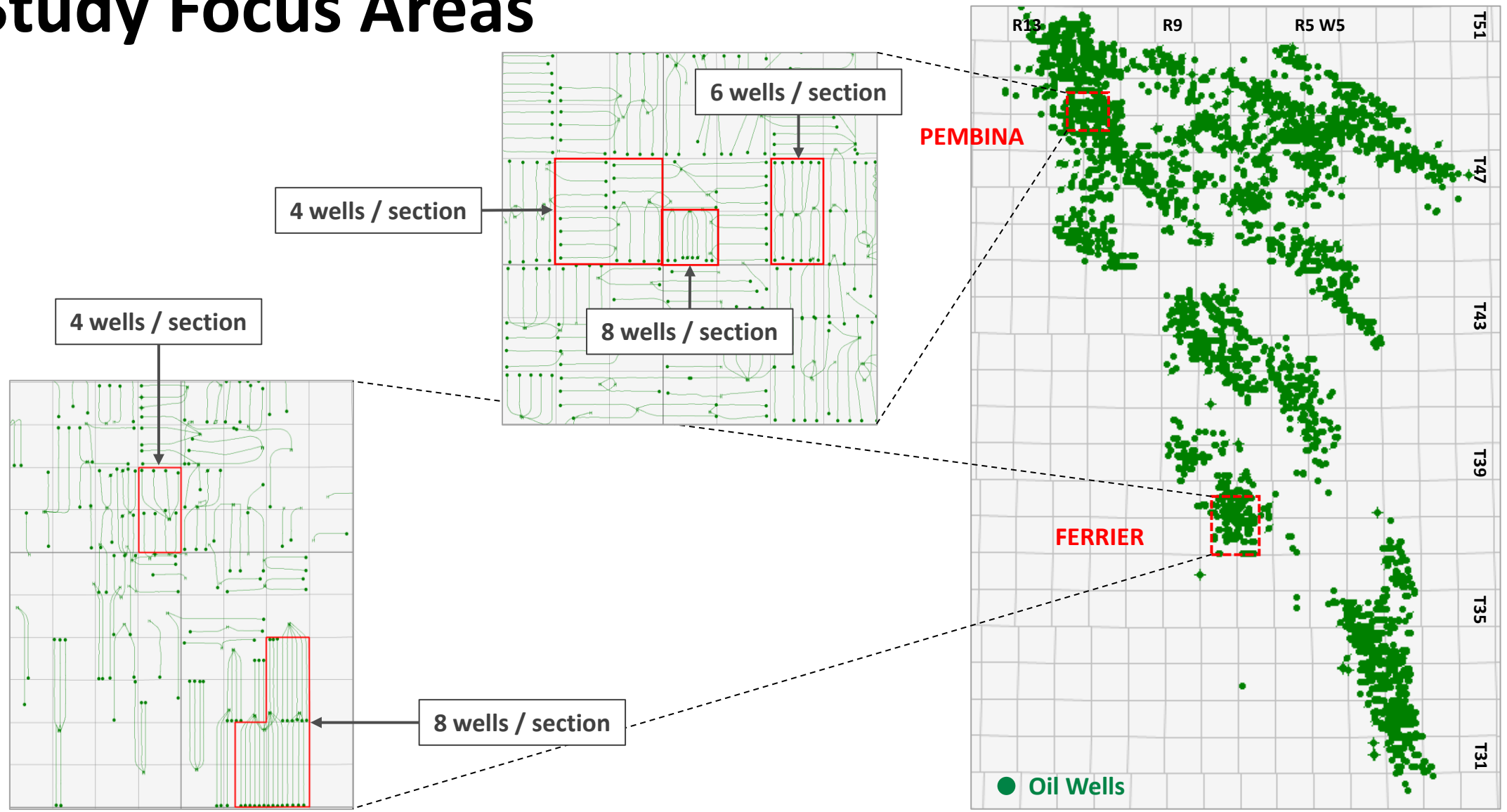


General Geology

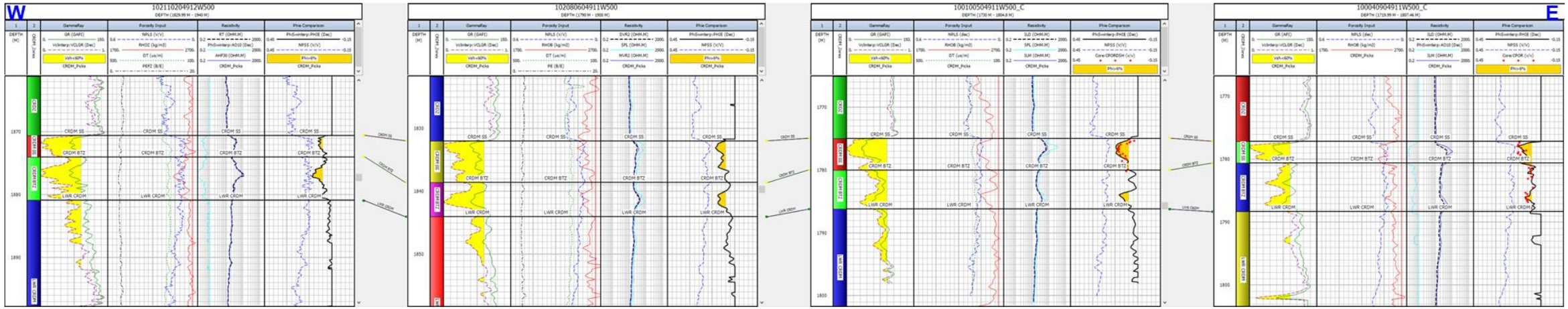
- Cardium formation deposited during Late Cretaceous in a shoreface-to-shallow marine environment along a NW-SE trending shoreline (CDL, 2010).
- The dominant rock types are sandstones, mudstones and localized conglomerate.
- The geology is highly variable, but can be divided into four reservoir types:
  - **Main Sand:** Fine-to-medium grained sandstone. Good storage capacity and permeability.
  - **Bioturbated Zone:** Highly bioturbated, very fine-grained sandstone, siltstone and mudstone. Good storage capacity but low permeability.
  - **Lower Cardium:** Interbedded very fine-grained sandstone and mudstone. Low storage capacity and very low permeability.
  - **Conglomerate:** Highly variable thickness and lateral continuity. Low storage capacity but very high permeability.



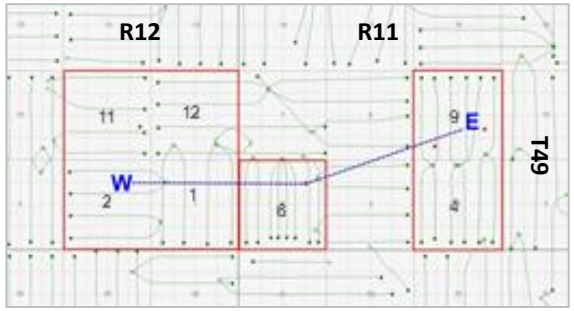
Study Focus Areas

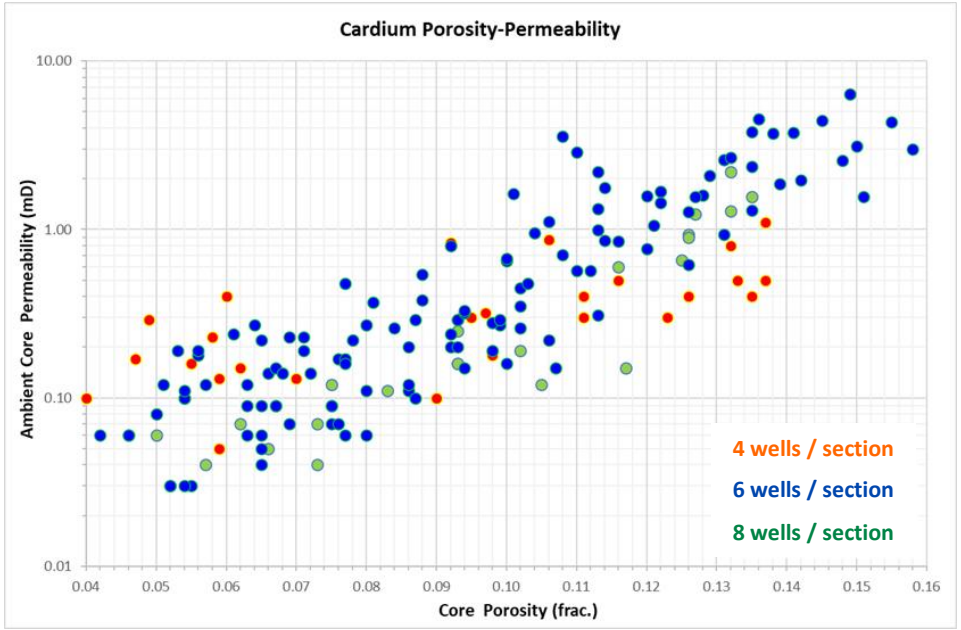


Pembina Area

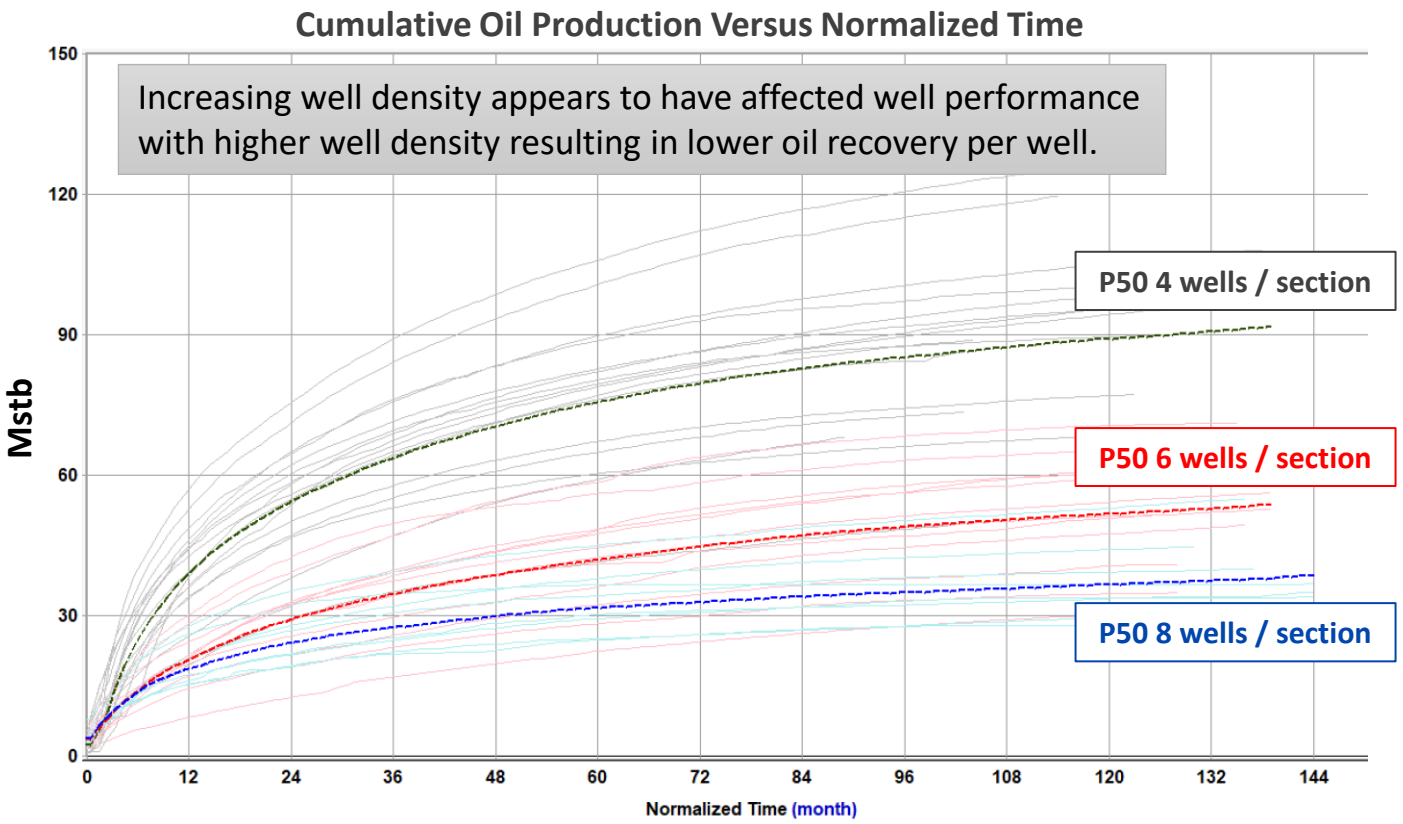


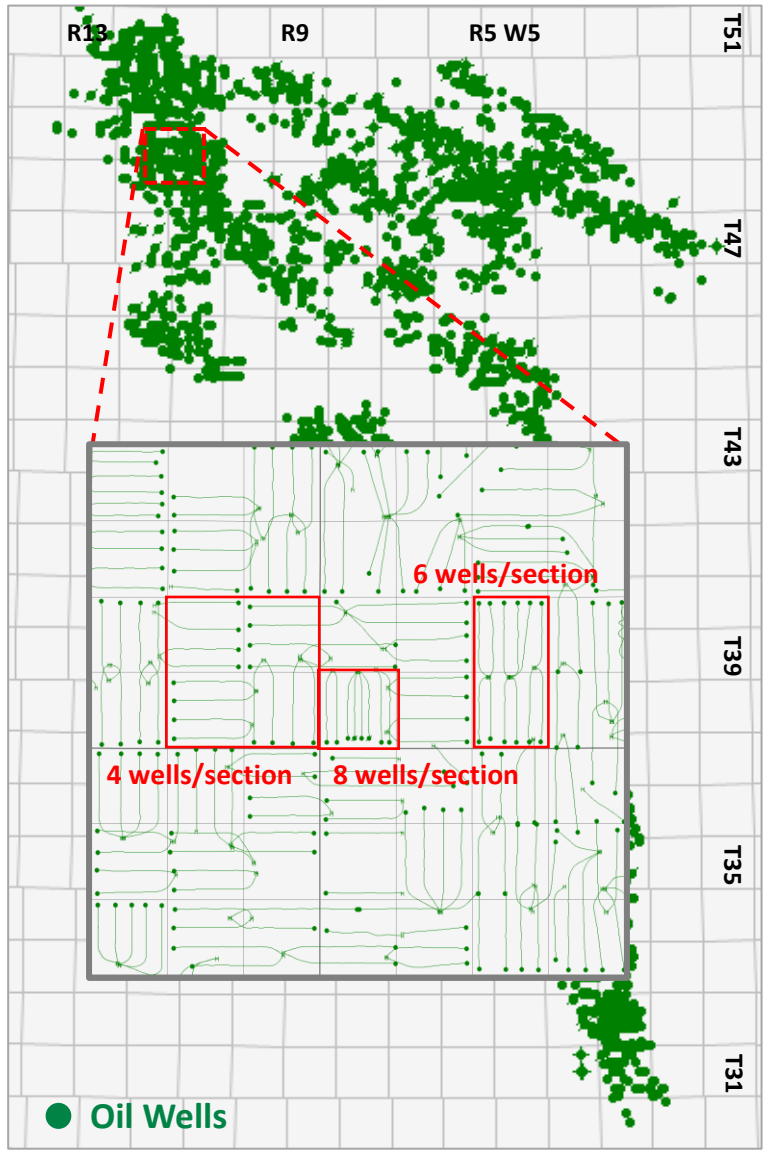
- The Pembina focus area shows similar petrophysical properties across the three focus areas.
- Rock quality is consistent, and permeability distribution is similar over all the sections.
- The focus area does not contain capping conglomerate.



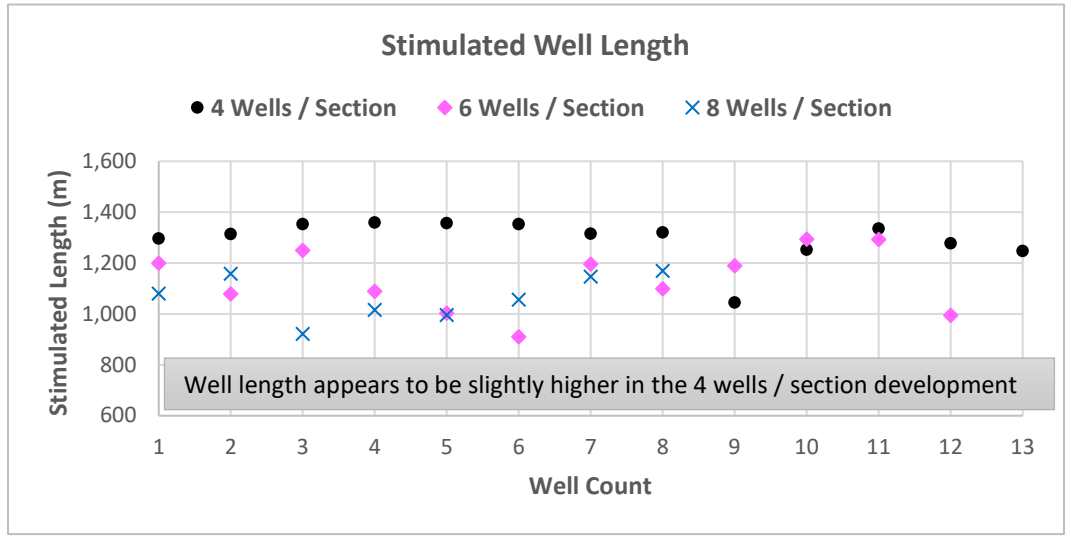


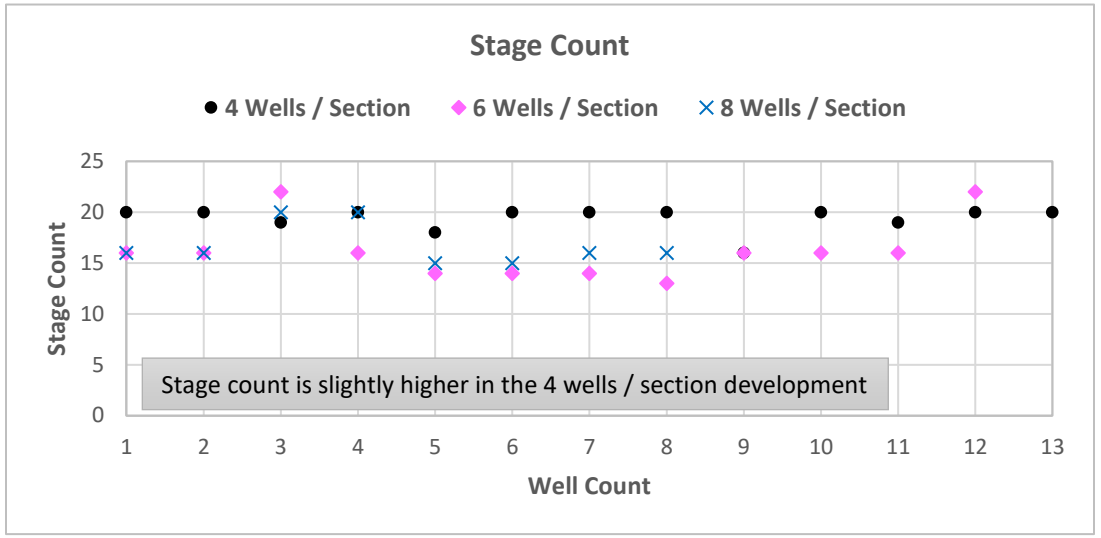
Pembina Well Performance

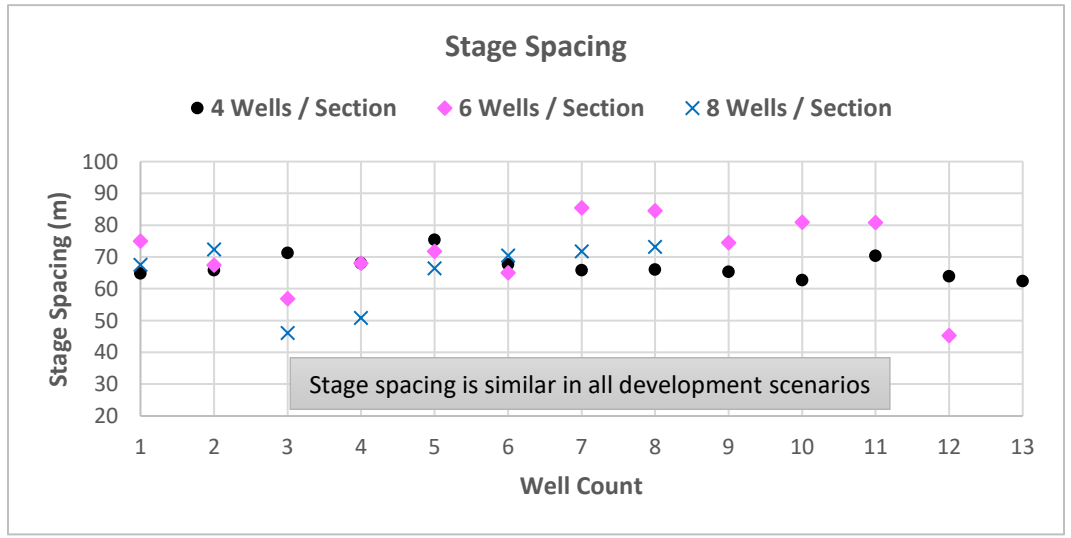


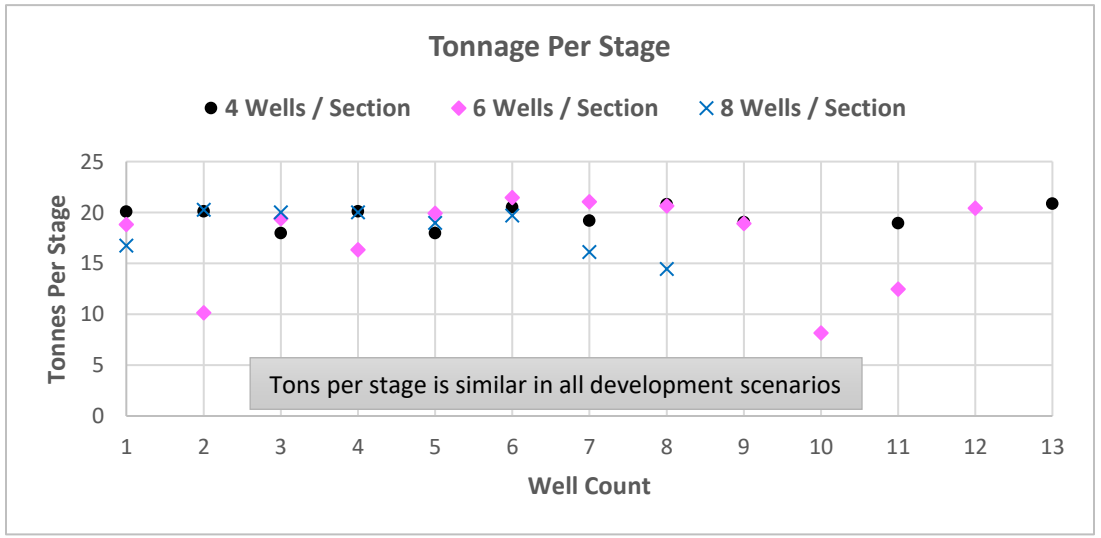


Pembina Focus Area – D & C Parameters

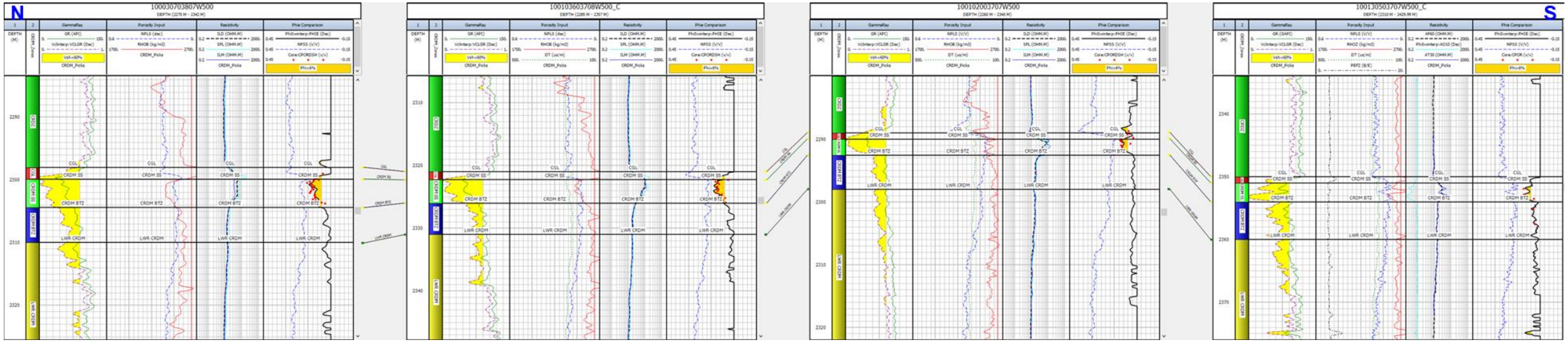




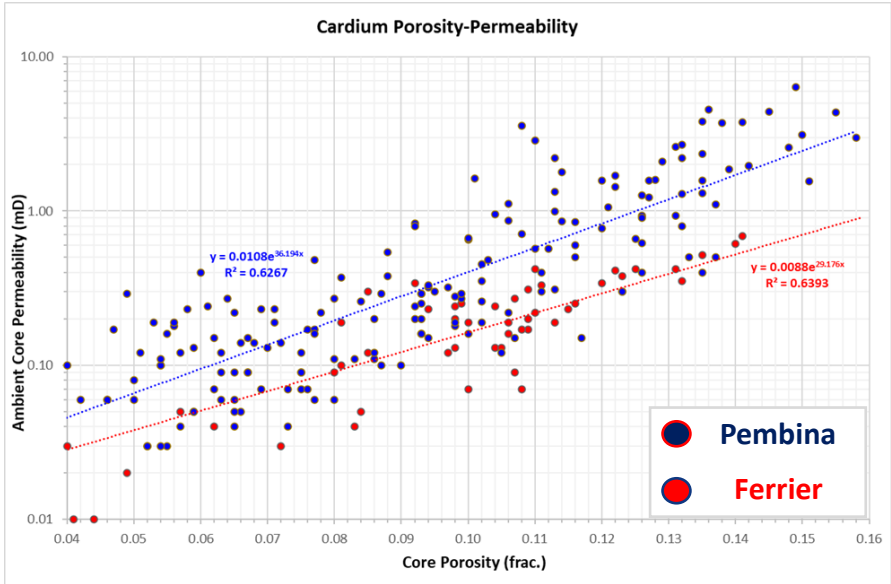




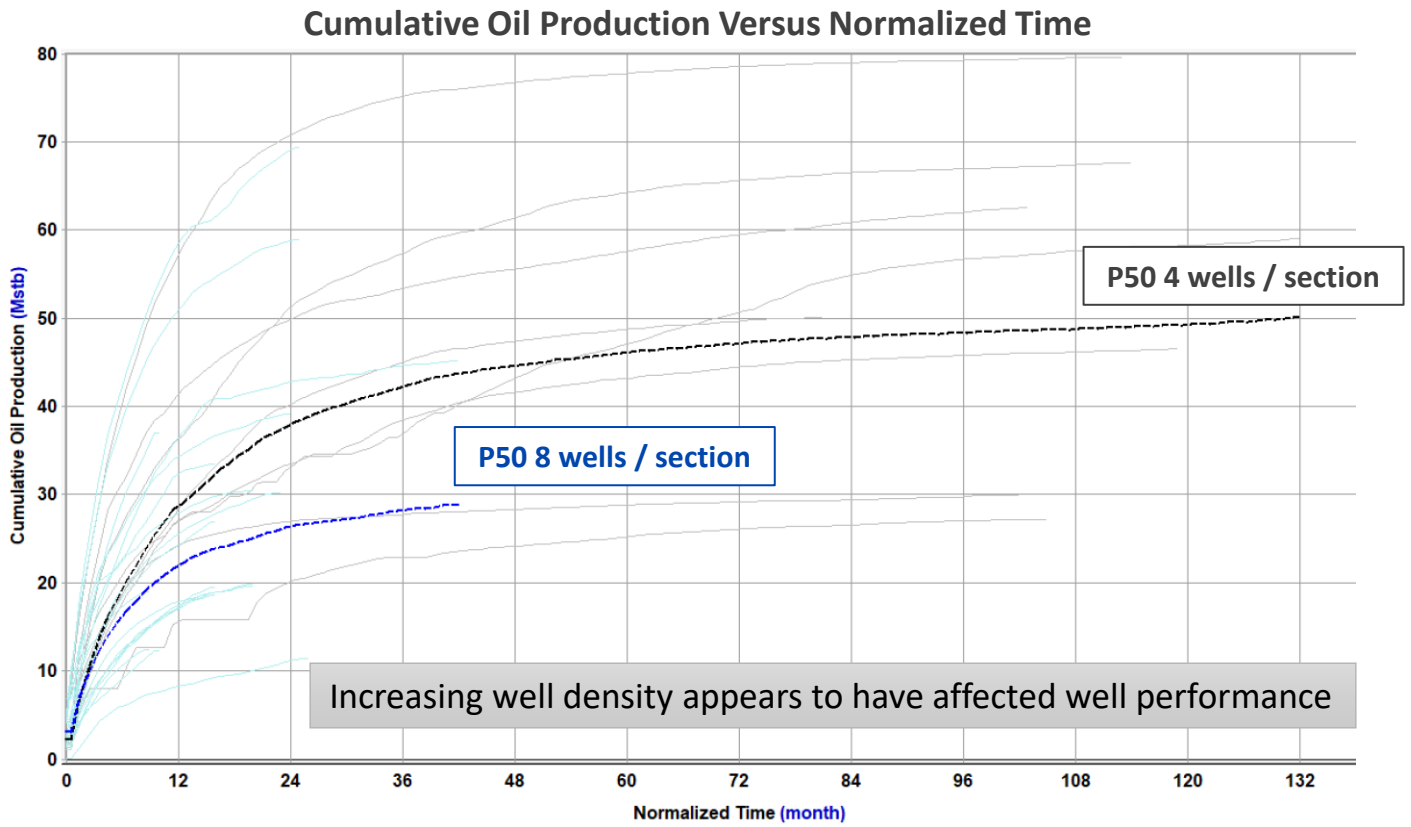
Ferrier Area

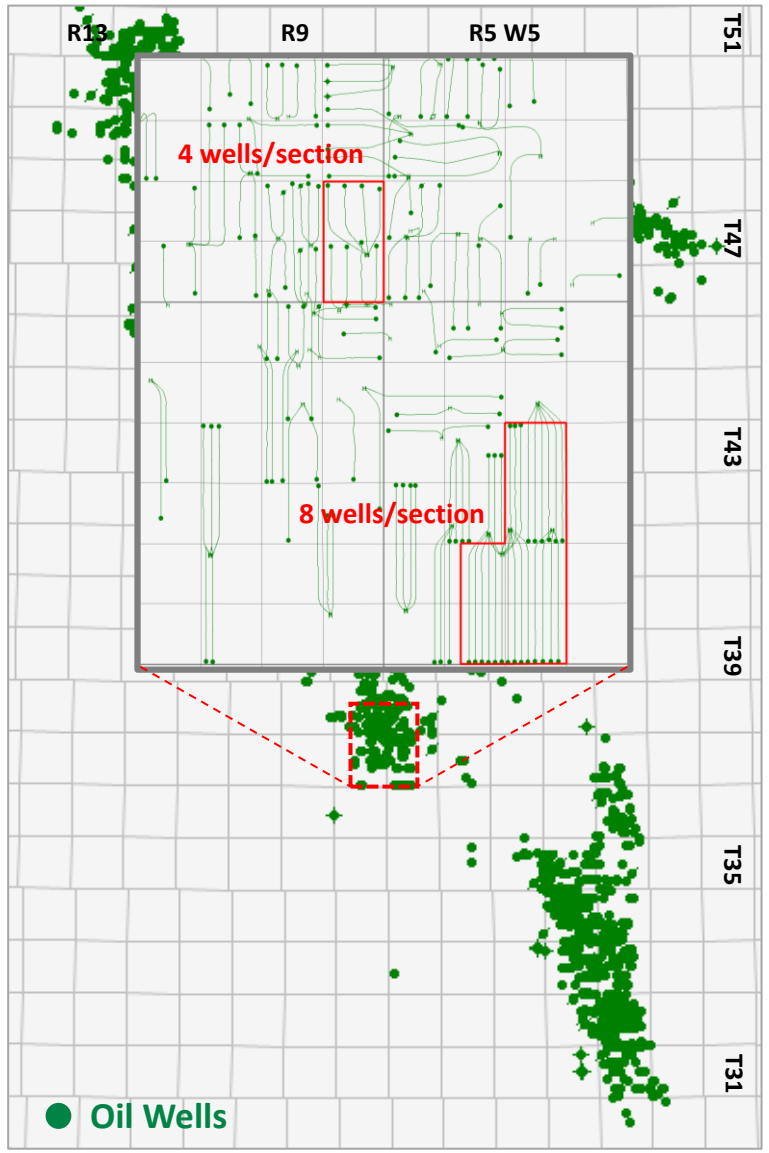


- Ferrier focus area has variations in petrophysical properties from North to South.
- Rock quality is better in northern sections compared to the southern sections.
- No distinct rock type difference however, Pembina area shows higher permeability.

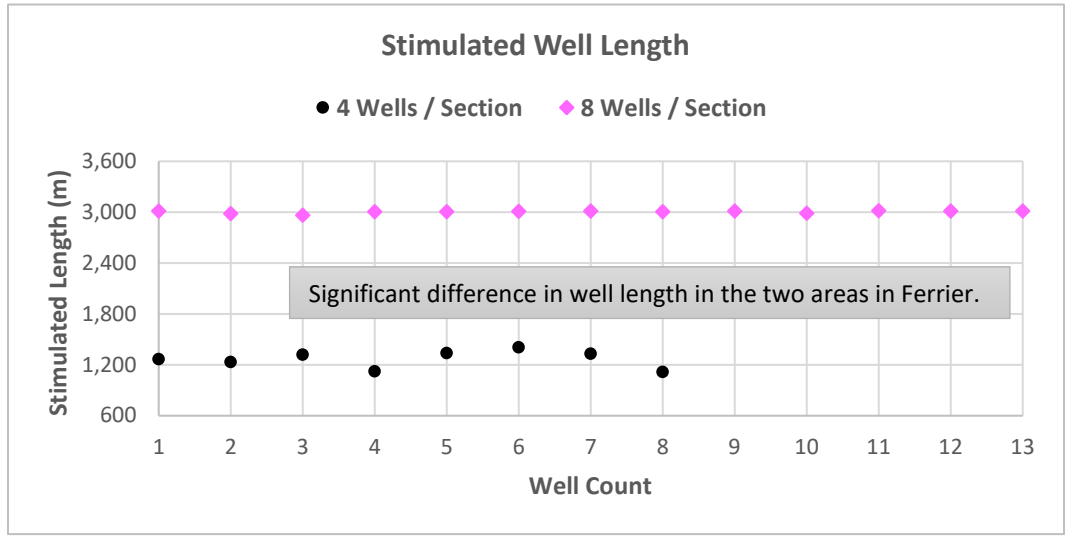


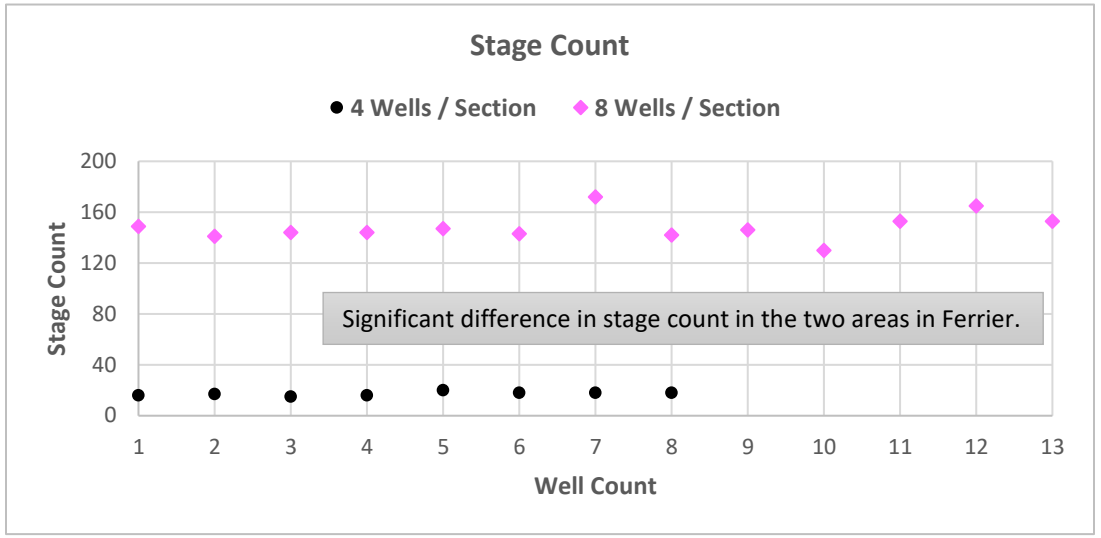
Ferrier Well Performance

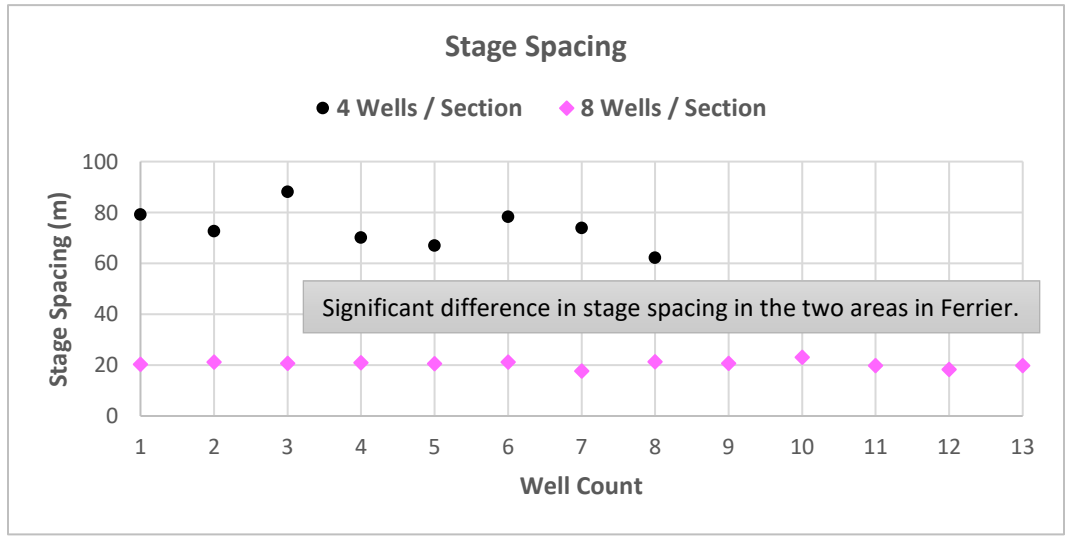


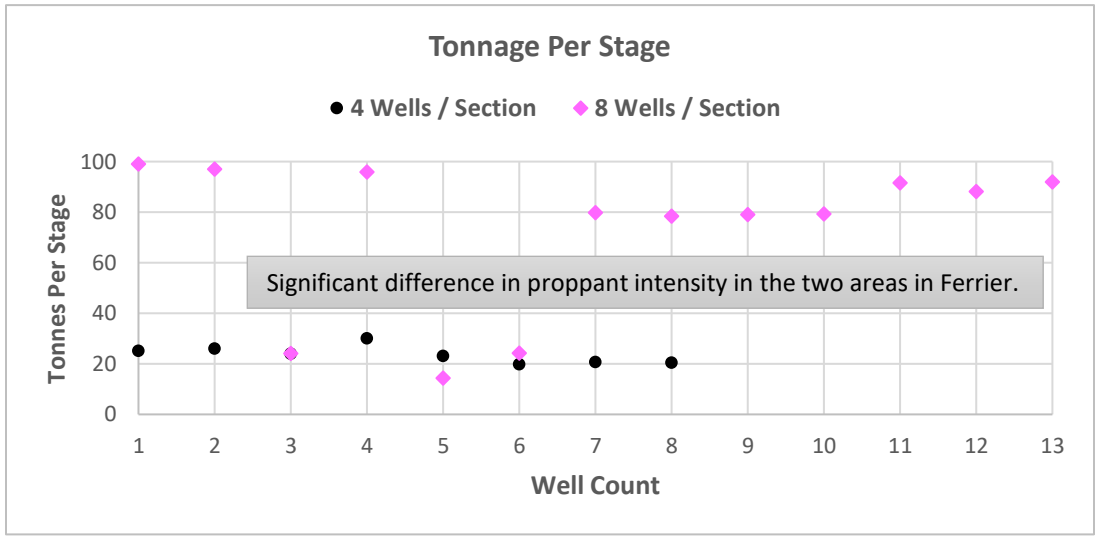


Ferrier Focus Area – D & C Parameters

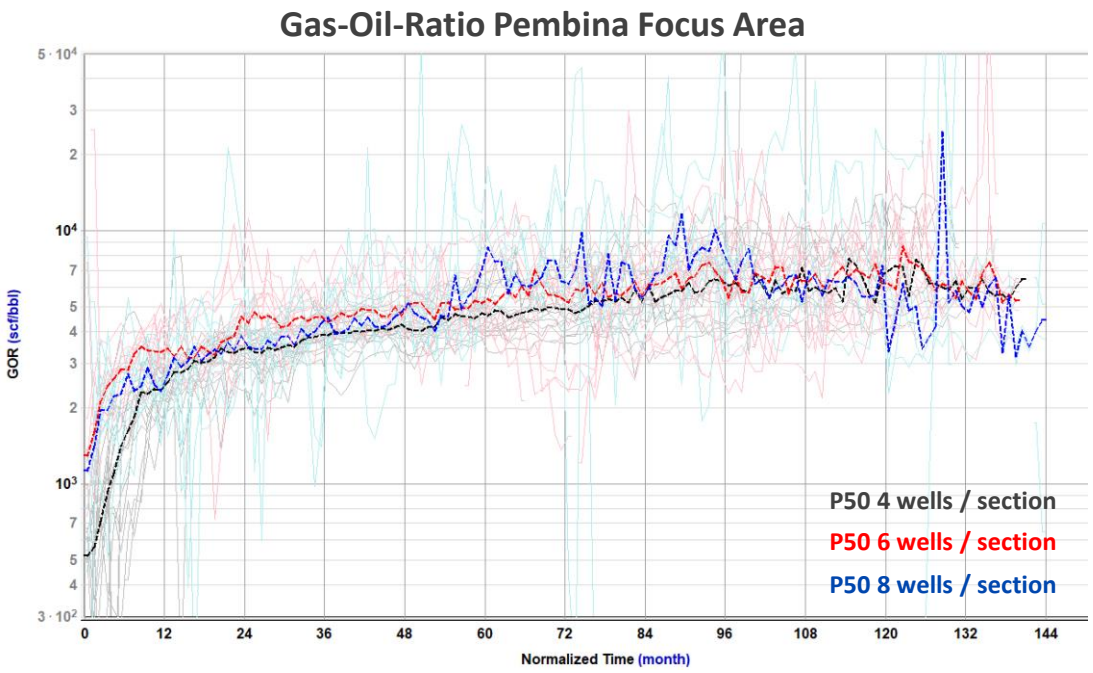




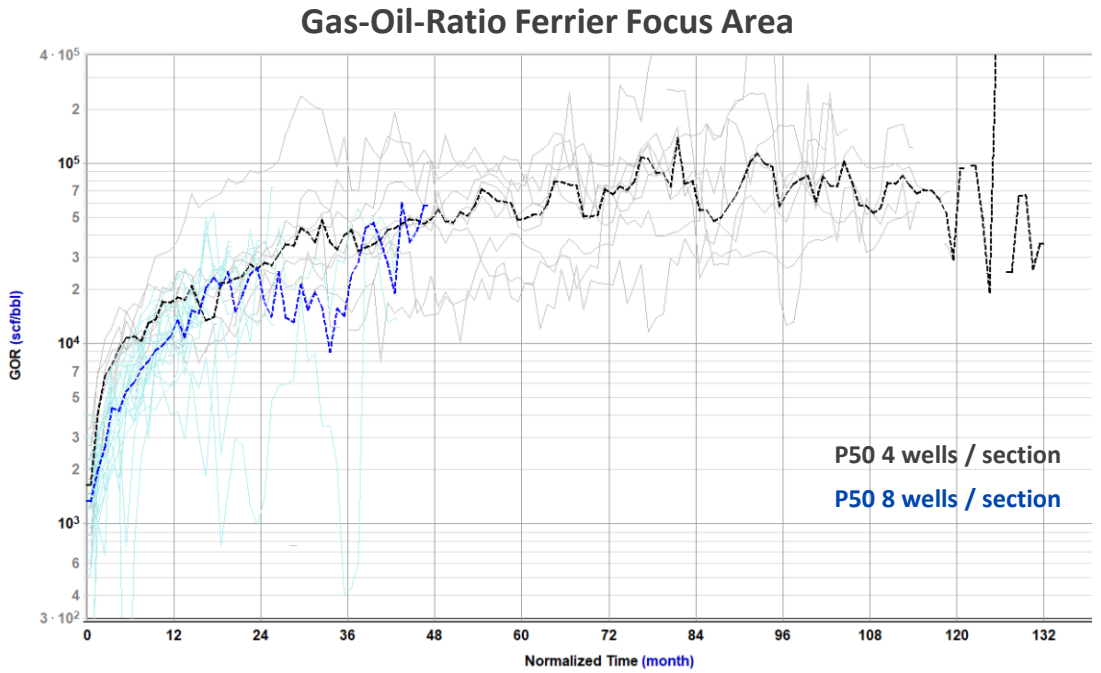




Gas-Oil-Ratio Comparison

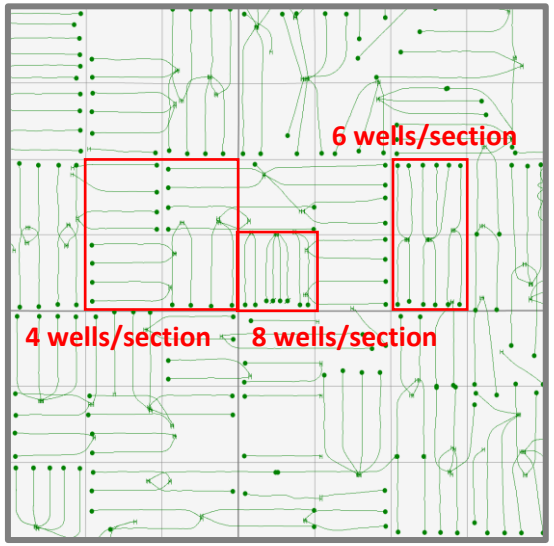


- GOR is similar across the focus areas, hence in-situ fluids appear to be similar also.
- Therefore, variation in in-situ fluid not driving differences in well performance.

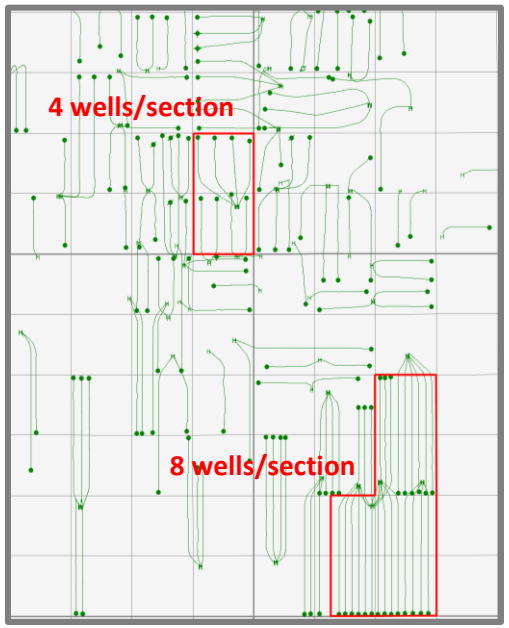


Recovery Factor Comparison

Pembina Focus Area



Ferrier Focus Area



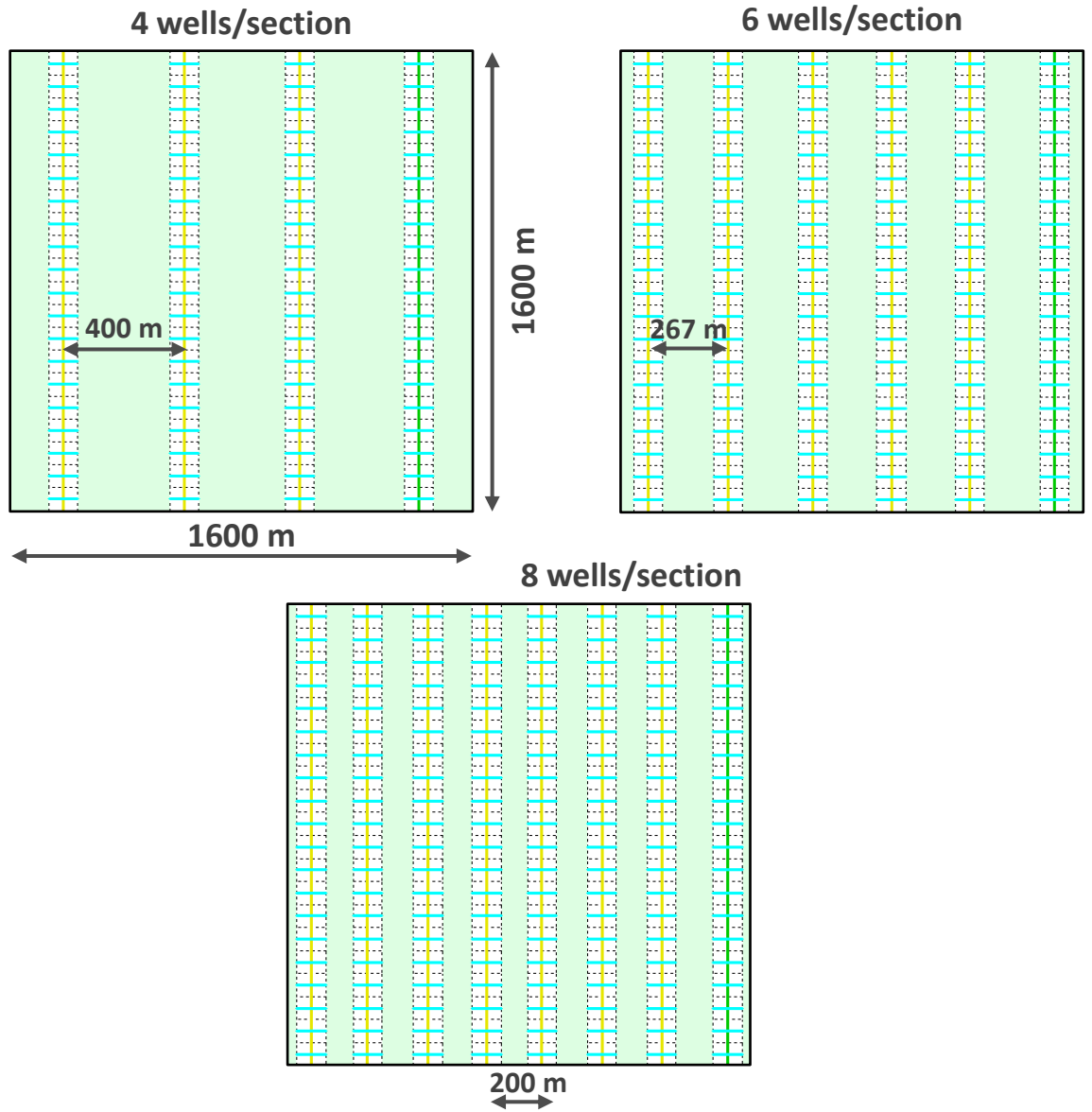
Pembina Focus Area					
Development Strategy	STOOIP / Section (MMBbls)	EUR Per Well (Mstb)	RF (%)	Adjusted EUR Per Well (Mstb)[1]	Adjusted RF (%)
4 Wells Per Section	4.2	90	8.5	75[2]	7.2
6 Wells Per Section	4.6	55	7.2	55	7.2
8 Wells Per Section	4.5	40	7.2	40	7.2

Ferrier Focus Area					
Development Strategy	STOOIP / Section (MMBbls)	EUR Per Well (Mstb)	RF (%)	Adjusted EUR Per Well (Mstb)[1]	Adjusted RF (%)
4 Wells Per Section	4.1	50	4.9	90[3]	4.3
8 Wells Per Section	1.5	35	9.5	4[4]	1.0

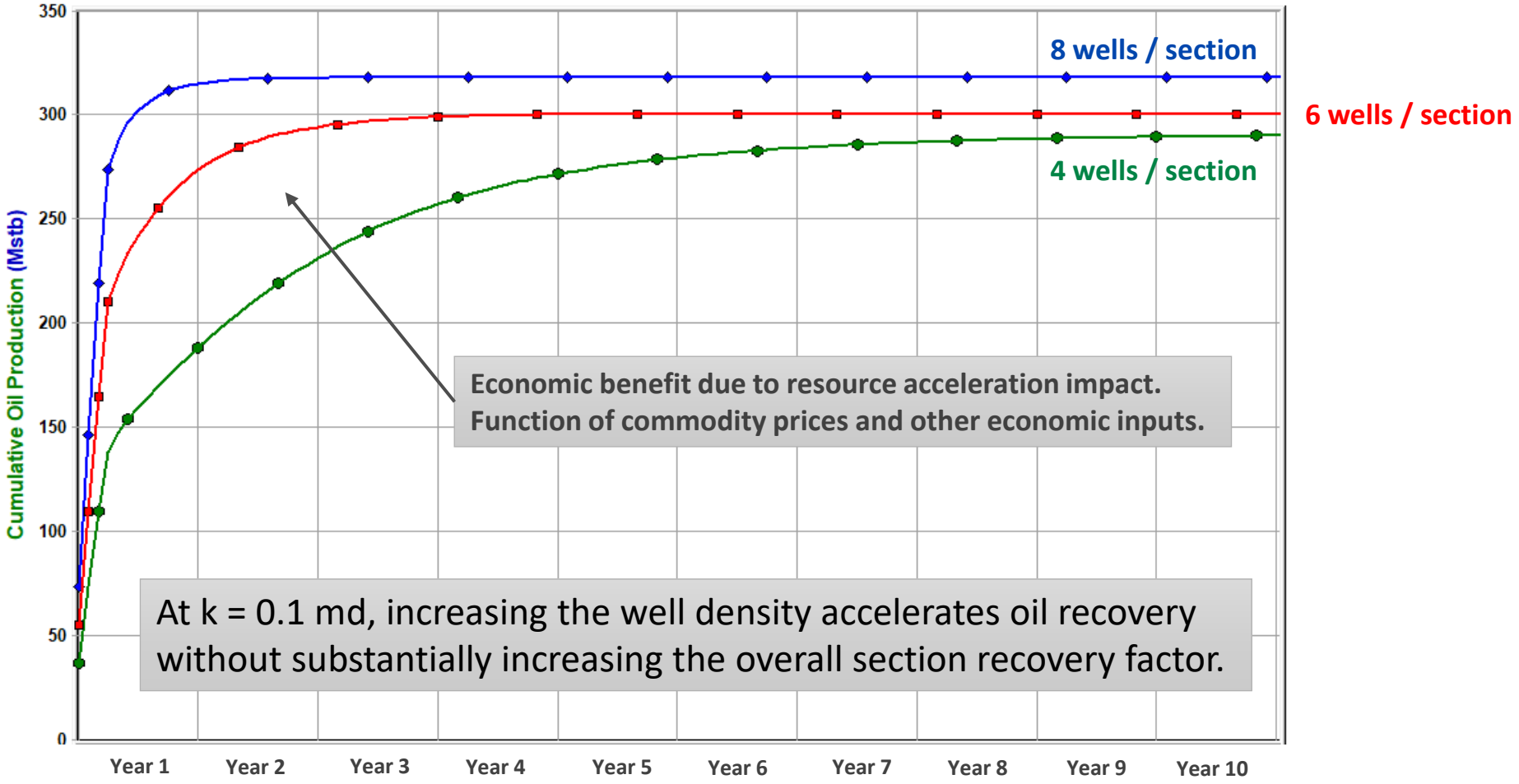
[1]Adjustment for variation in D&C parameters.
[2]Adjustment applied for reduced lateral length of 1,100 m.
[3]Adjustment applied for increased well length of 3,000 m by a factor of 1.75.
[4]Adjustment applied for reduced number of stages similar to the 4 wells per section case.

Reservoir Modelling

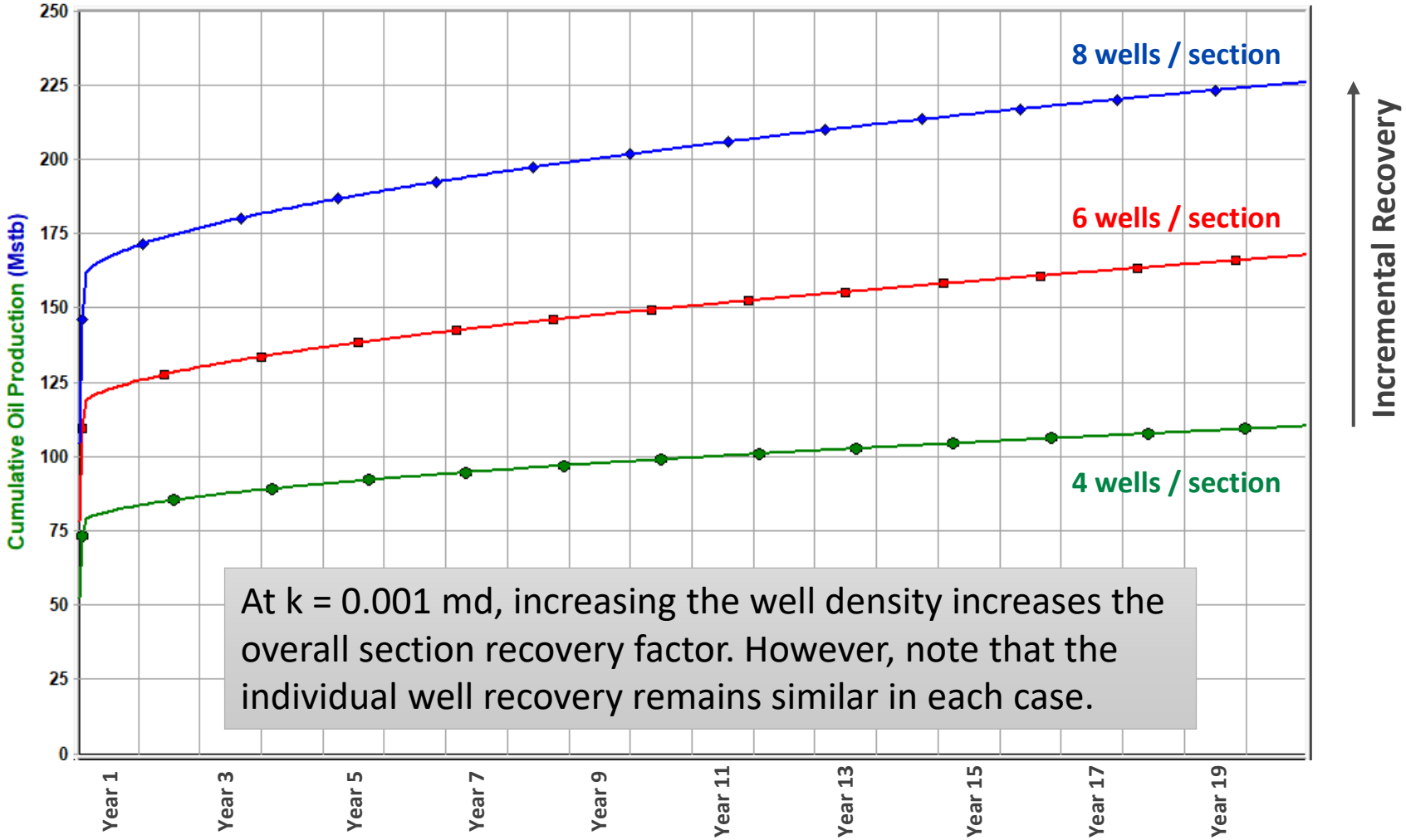
- Single section model with varying well densities.
- Matrix permeability = 0.1 & 0.001 md
- Number of fractures = 20
- Fracture half-length = 50 m
- Observe impact on ultimate recovery and recovery per well.
- Single layer model:
  - STOOIP = 4 MMBbls



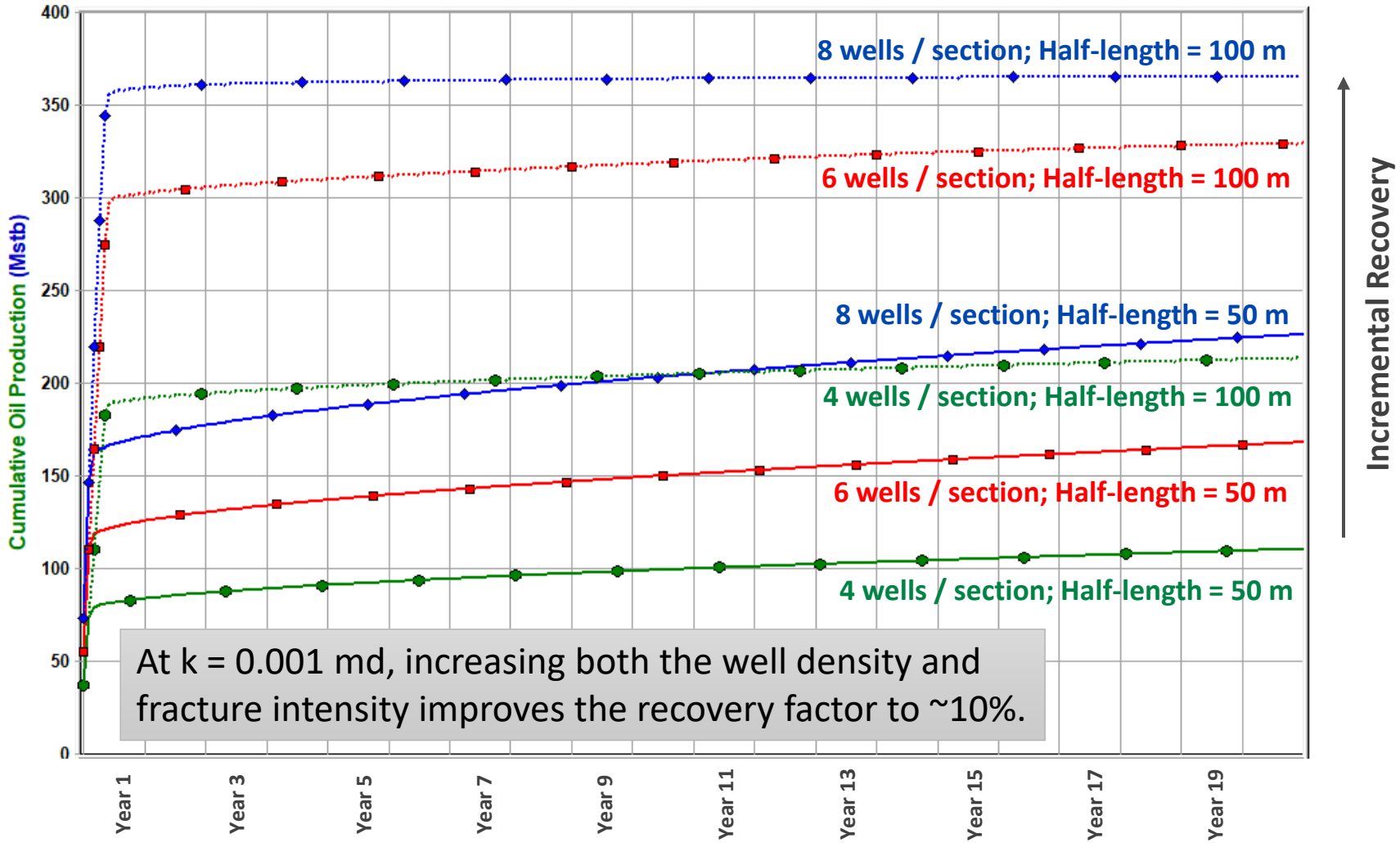
Recovery Factor Sensitivity To Well Density (k = 0.1 md)



Recovery Factor Sensitivity To Well Density (k = 0.001 md)



Recovery Factor Sensitivity To Fracture Intensity (k = 0.001 md)



Conclusions

- The Cardium formation in WCSB has mainly been developed at a well density of 4 wells per section. However, in some areas, higher well densities of up to 8 wells per section has been employed.
- Rock quality seems to be the main driver for well performance and overall recovery factor obtained from the section in the various development scenarios.
- Where the rock quality is better ($k \approx 0.1$ md), 4 wells per section is adequate to effectively drain the entire section. In this case, higher well density is accelerating oil recovery without significantly increasing the overall recovery factor.
- Where the rock quality is poor ($k < 0.001$ md), higher well densities of up to 8 wells per section with more intense hydraulic fracturing is necessary to effectively drain the entire section and increase the overall recovery factor to around 10%.