



HORN RIVER BASIN

Subsurface Aquifer Characterization Project

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ACKNOWLEDGEMENTS

- Horn River Basin Producers Group
 - Apache
 - ConocoPhillips
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 - Canadian Discovery Ltd.
 - JC Consulting Inc., JMS Geological Consulting

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT

INTRODUCTION

- Horn River Basin Devonian shale gas play is one of North America's largest and hottest shale gas "resource" plays
 - All acreage is subject to intensive development by multi-leg horizontal wells, each leg stimulated by multiple staged fracs
- Large volumes of water will be required – up to 4000m³ per frac
 - Spent (contaminated) frac waters must be safely disposed
- Deep subsurface aquifers are ideal sources and sinks
 - Non-potable water, far below water table and surface waters
 - Shallower aquifers, such as Quaternary (glacial) paleovalleys, may represent short-term water sources, but may not be suitable for disposal
 - Producers do not want to use surface water sources, and cannot dispose of spent fluids at the surface

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT

PROJECT OBJECTIVES and GOALS

OBJECTIVE:

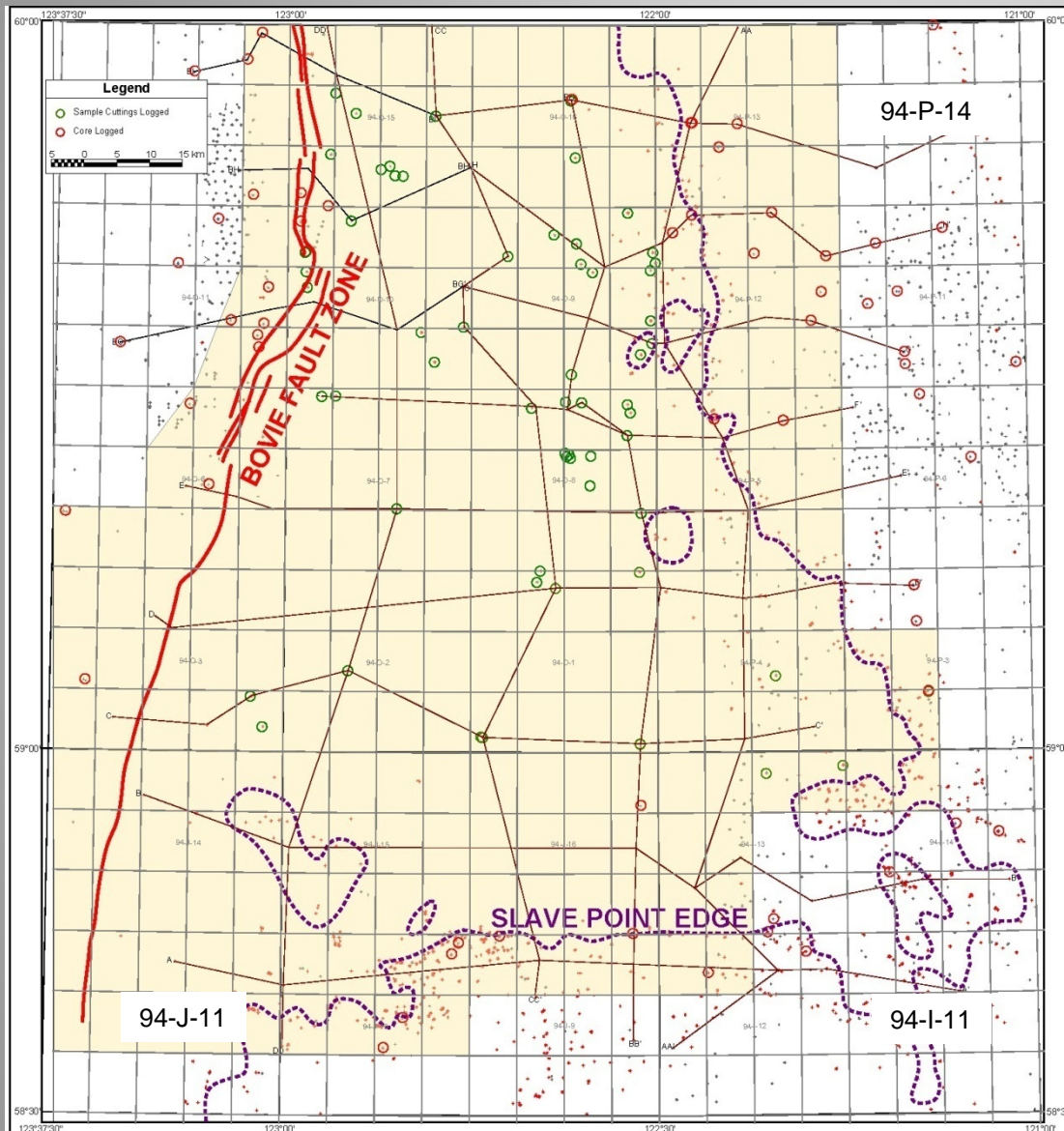
- Determine distribution and capacity of deep subsurface, non-potable aquifers in the HRB as:
 - Potential sources of water for shale gas completions
 - Potential disposal sites for water produced during shale gas completions and production

GOALS:

- To contribute information to help in planning the orderly development of the HRB shale gas resources
- To help reduce the overall environmental impact of unconventional gas development in the HRB

NOTE:

- This project complements other water-related research work being developed by HRBPG, including water recycling, and surface water quality and budget monitoring and assessment



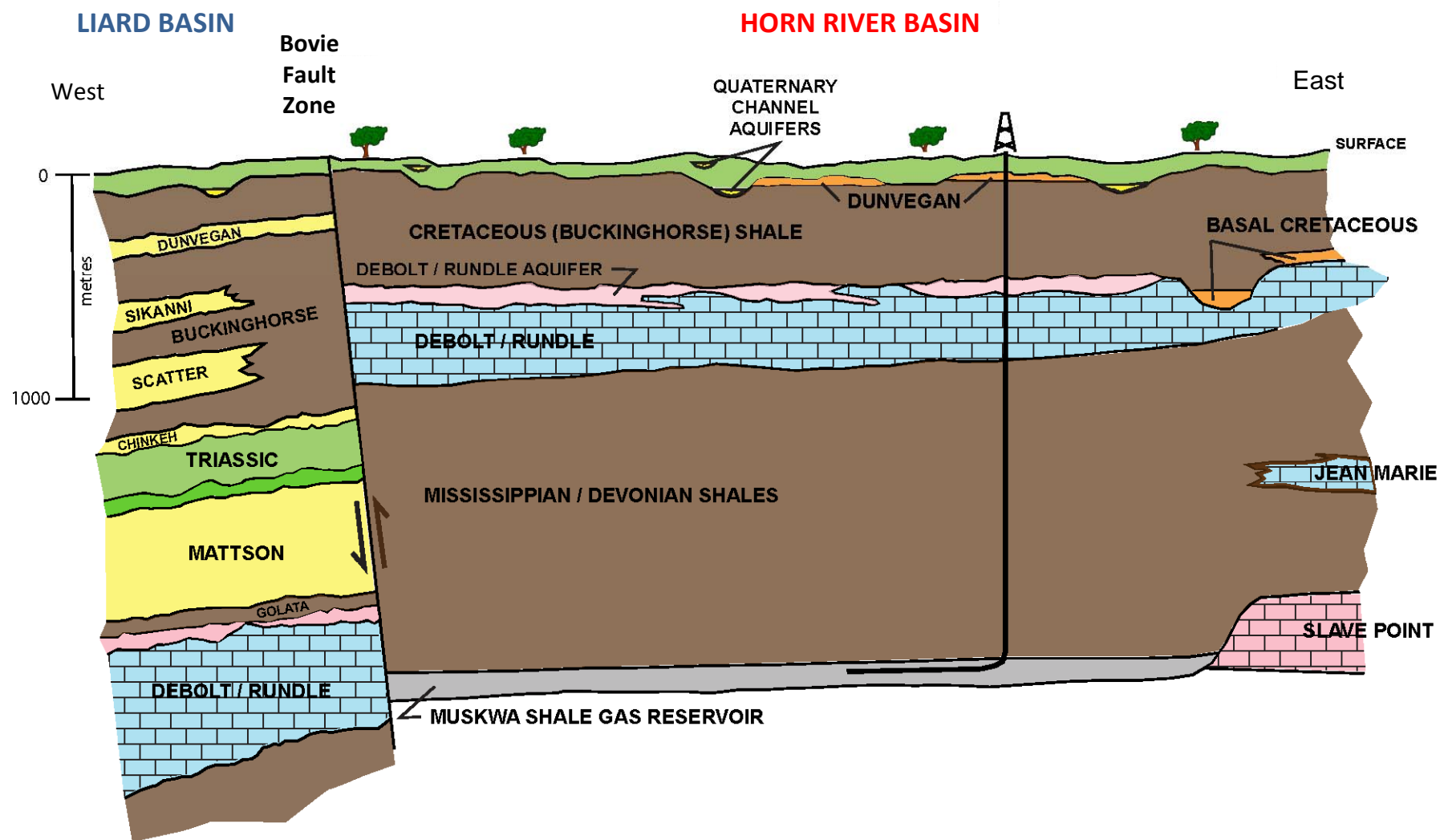
HORN RIVER BASIN

- Slave Point / Keg River platform to south and east
- Bovie Fault Zone to west

AQUIFER PROJECT DATA

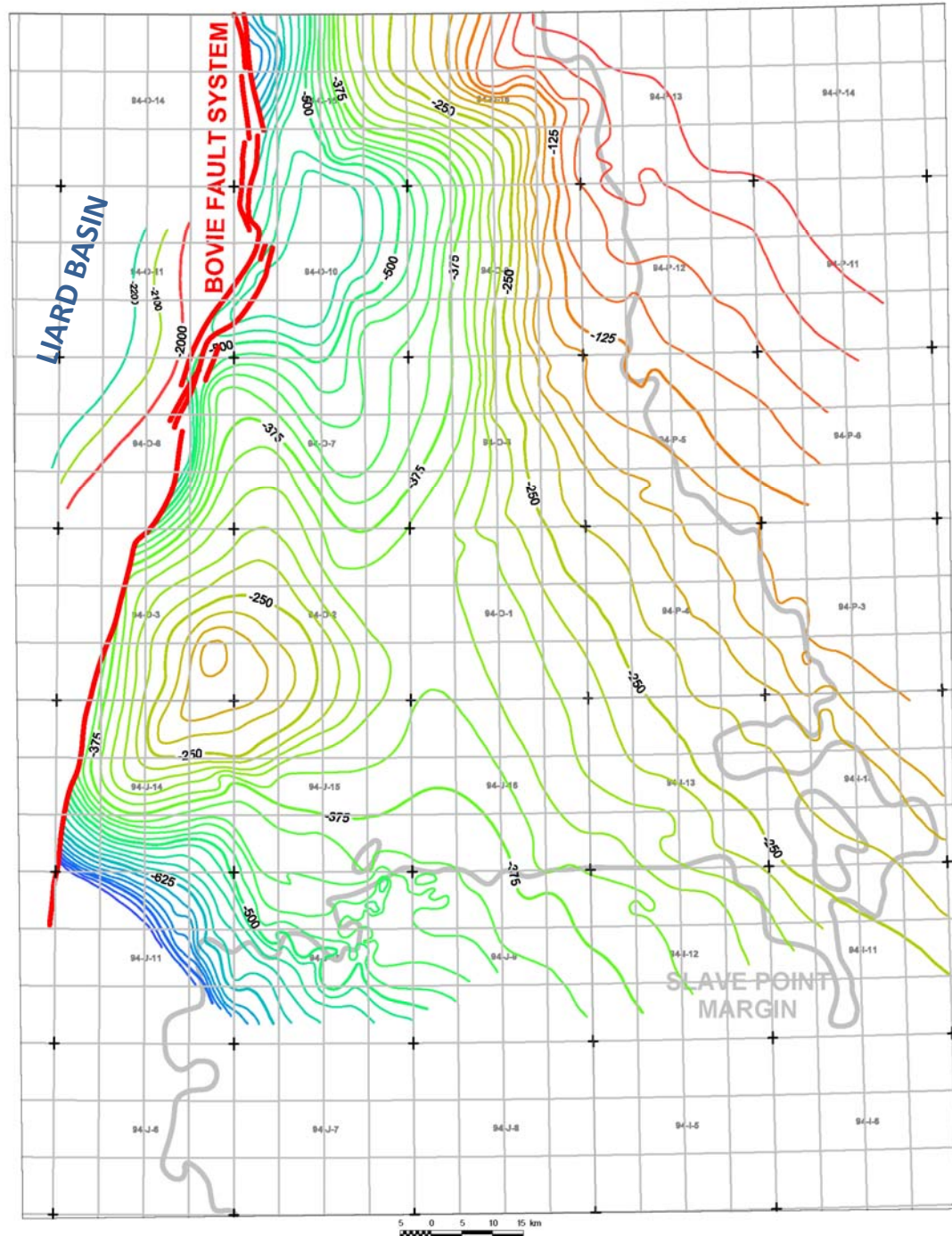
- 556 wells
- 16 regional cross-sections
- 60 cores logged
- Sample cuttings from 63 wells
- DST and water test data
 - numerous tests outside the basin to establish regional trends

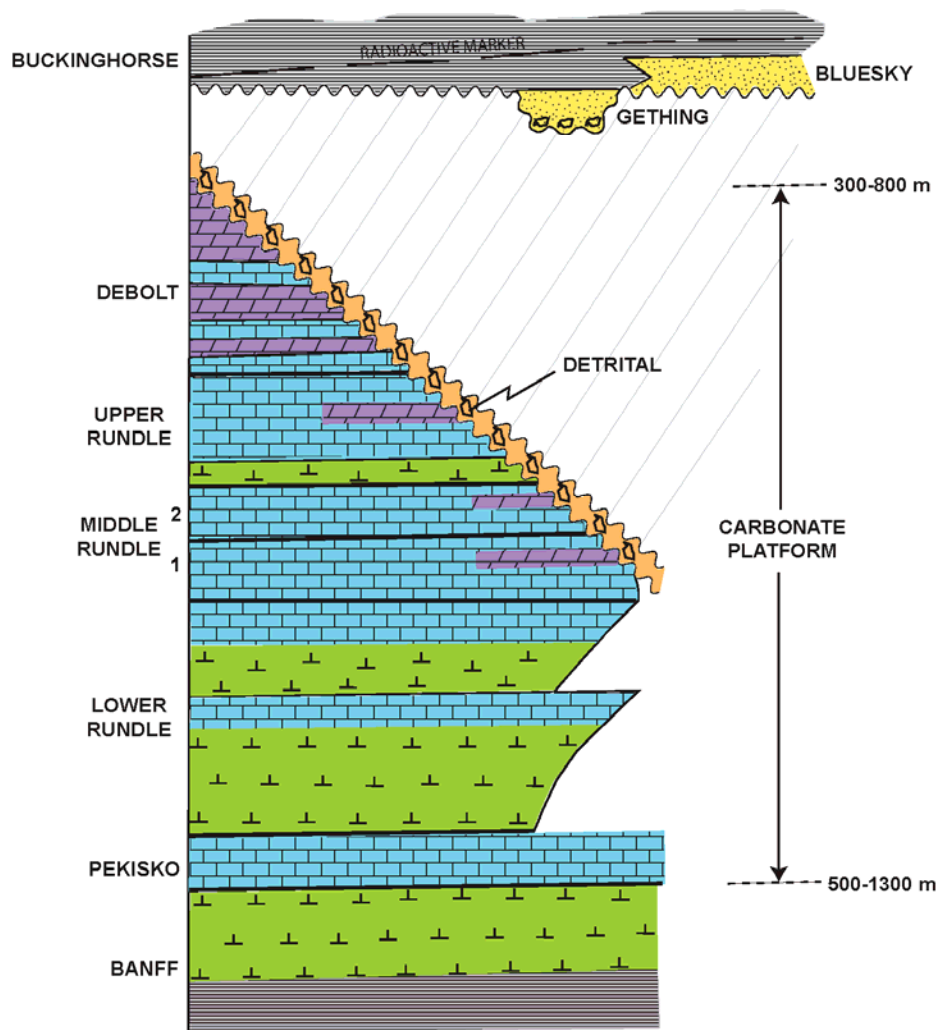
HORN RIVER BASIN SCHEMATIC CROSS-SECTION



STRUCTURE TOP BANFF FM

- Much deeper westward in Liard Basin (across Bowie Fault System)





HORN RIVER BASIN PRIMARY RESERVOIR UNITS

- **Mississippian carbonate platform**
 - Local reservoir development within cycles
 - More consistent and higher-quality reservoir at upper surface in "Detrital" zone
- **Mattson sandstones** (not shown)
 - to west in Bovie Fault Zone and Liard Basin
- **Cretaceous sandstones**
 - Gething to east
 - Bluesky to southeast
 - Chinkeh (not shown) in Liard Basin



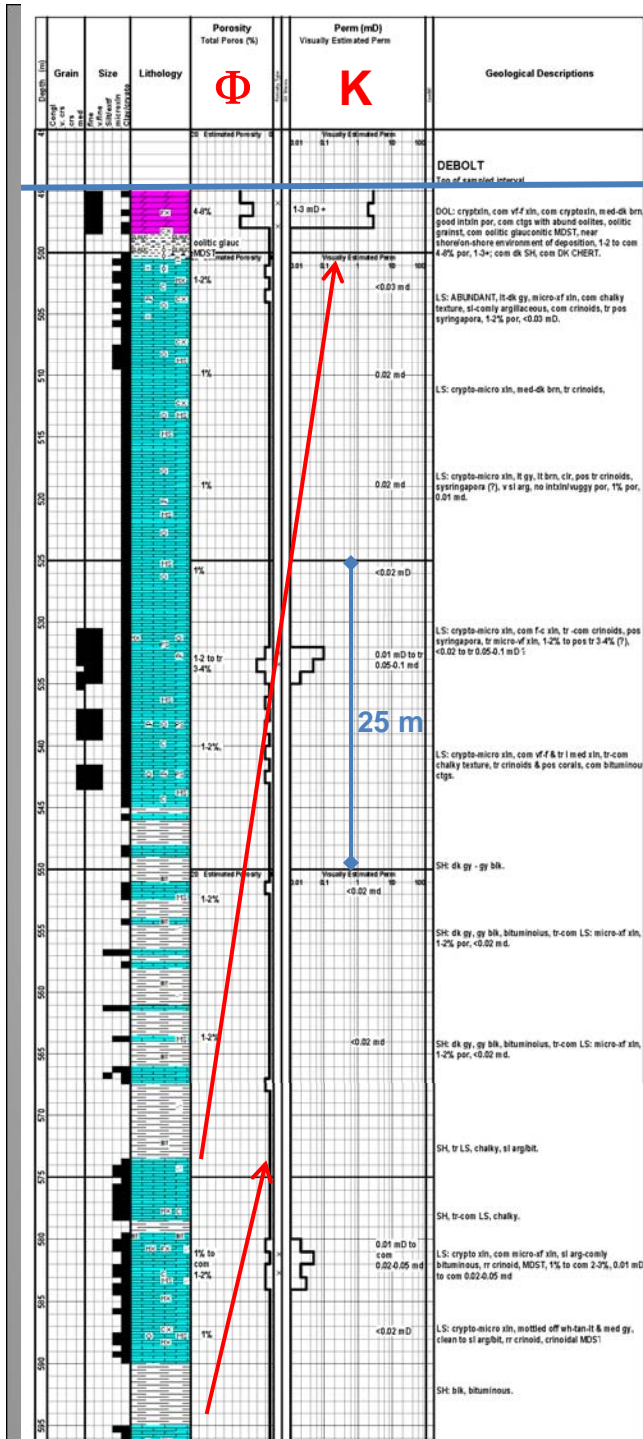
BANFF FORMATION

- Distal carbonate mudstones
- Limited clastic component (sltst – vf sst) to top
 - develops limited reservoir capacity where diagenetically enhanced at pre-Cretaceous unconformity
- **NOT** an aquifer target in Horn River Basin



PEKISKO FORMATION

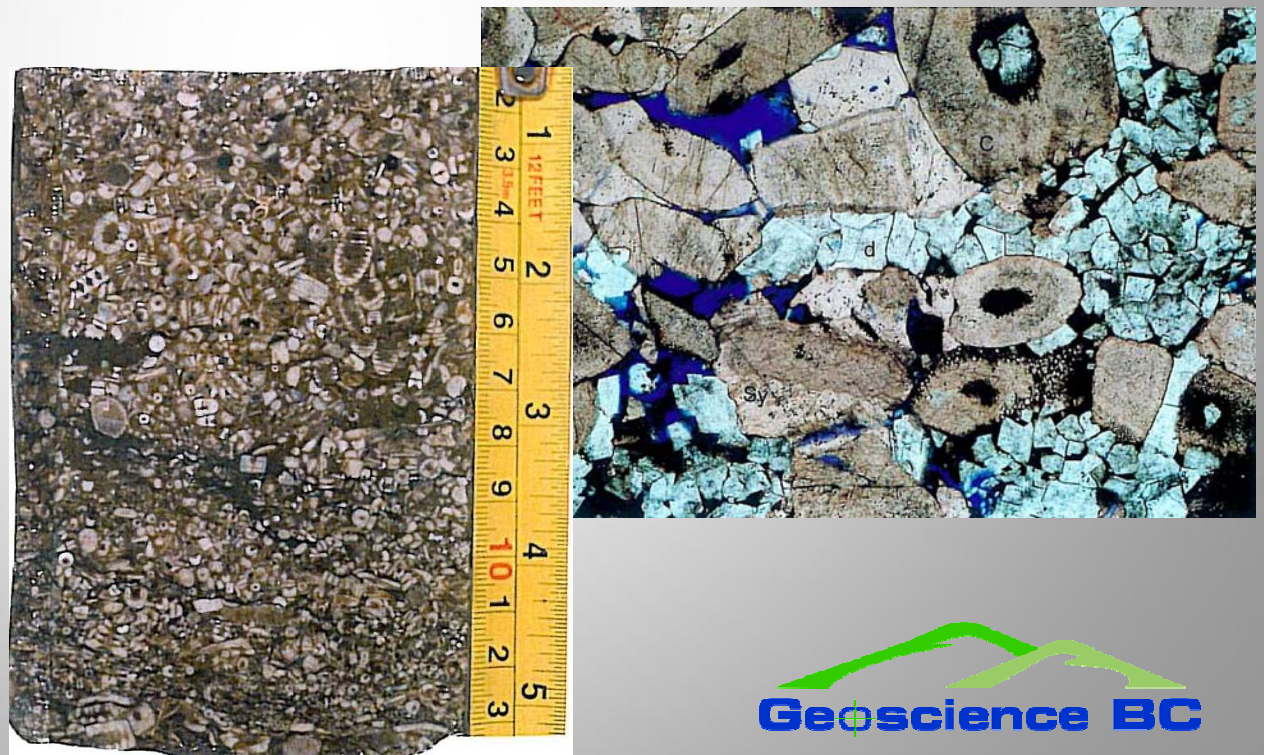
- Clean bioclastic limestone
- Marks base of Mississippian carbonate platform
- Tightly cemented, develops reservoir quality only locally beneath pre-Cretaceous unconformity
- **NOT** an aquifer target in Horn River Basin

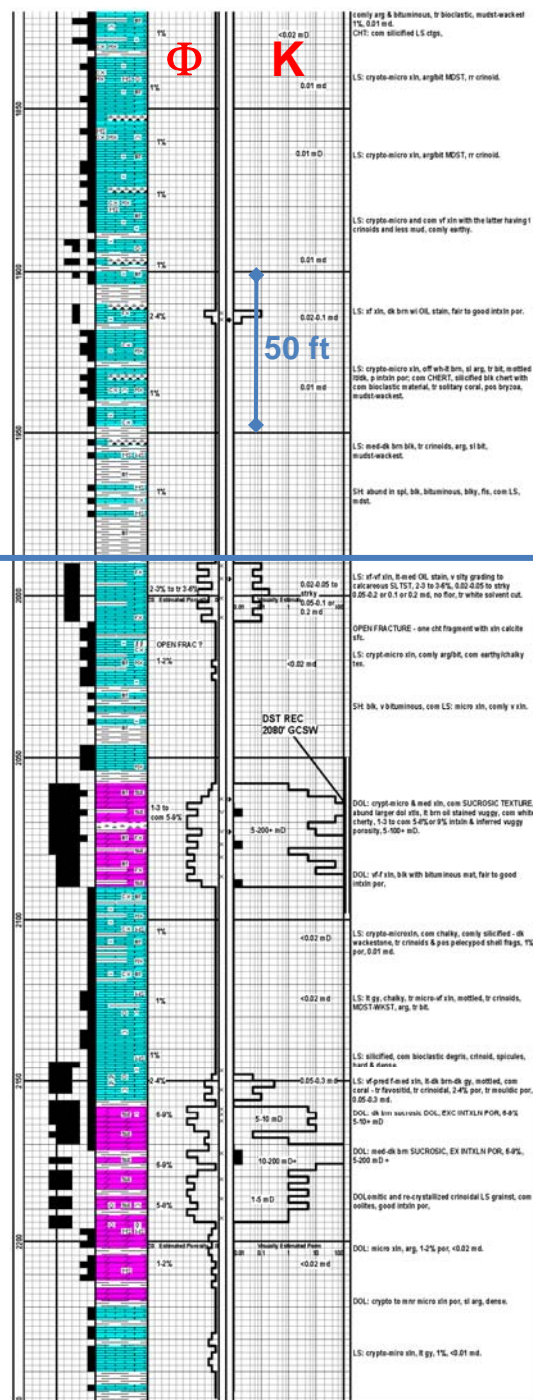


Debolt

RUNDLE / DEBOLT

- Correlated on flooding surface markers in Horn River Basin
 - Elkton / Shunda cannot be carried with confidence from southern areas
- Stacked shoaling-upward carbonate cycles form carbonate platform
 - dominantly mudstones to wackestones / packstones; little primary porosity
 - upper parts of cycles are dolomitized in middle of platform, in isolated wells





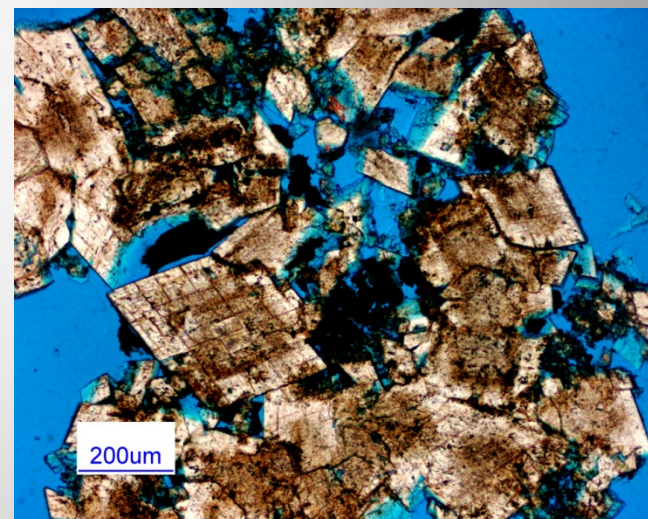
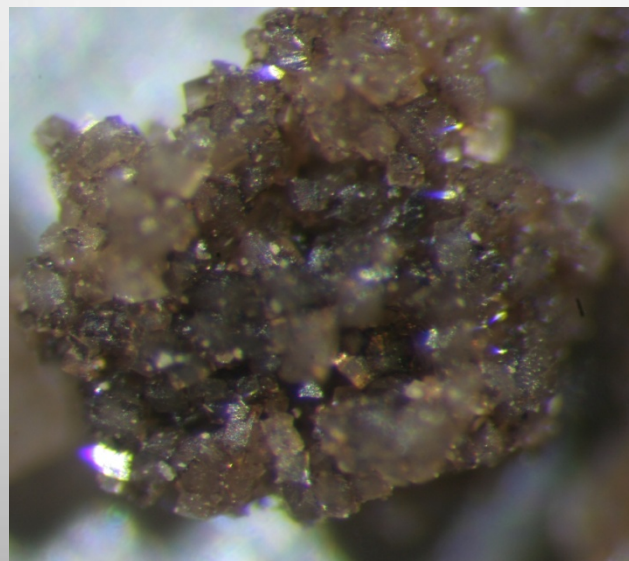
250' to pKU

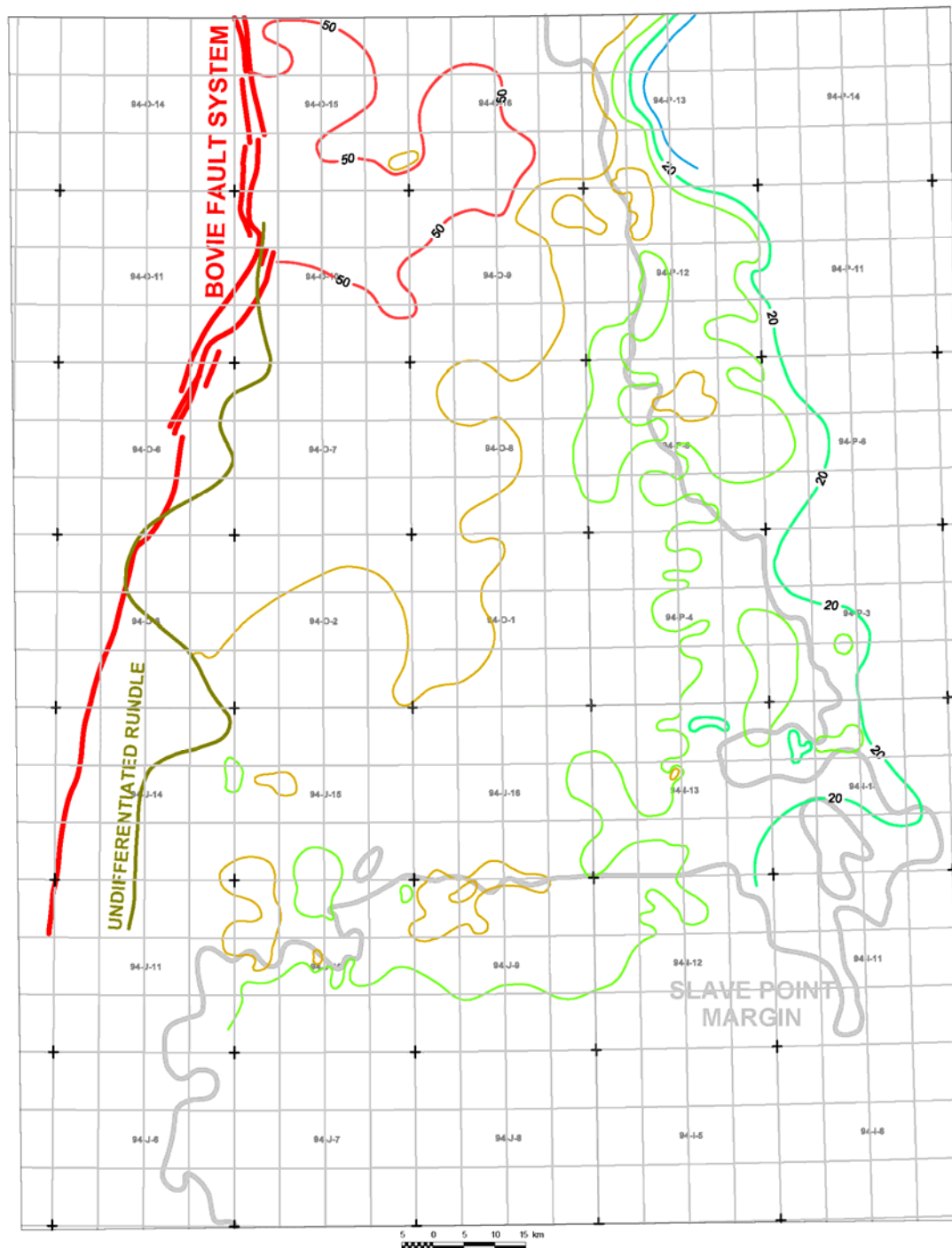
Debolt

Upper
Rundle

RUNDLE / DEBOLT

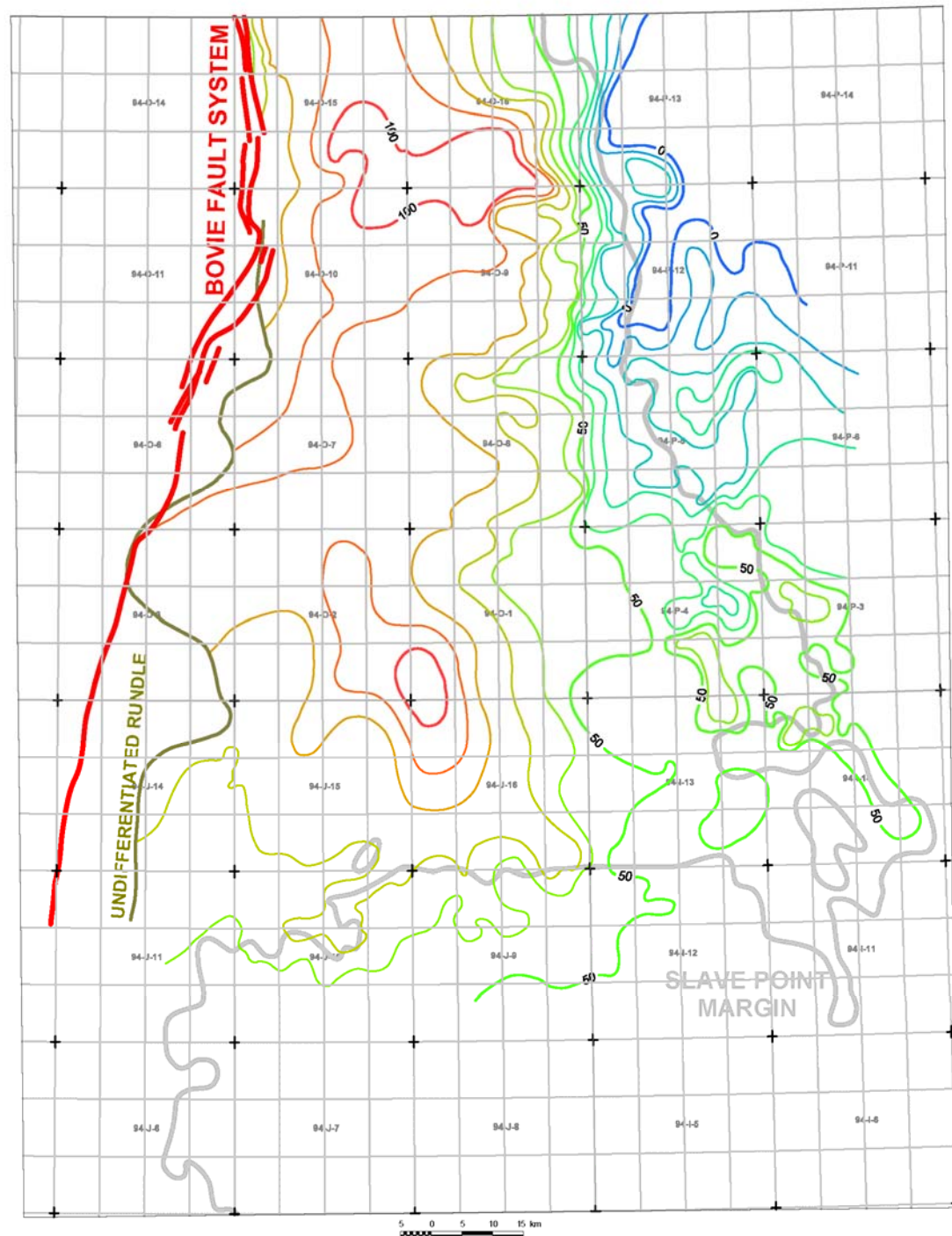
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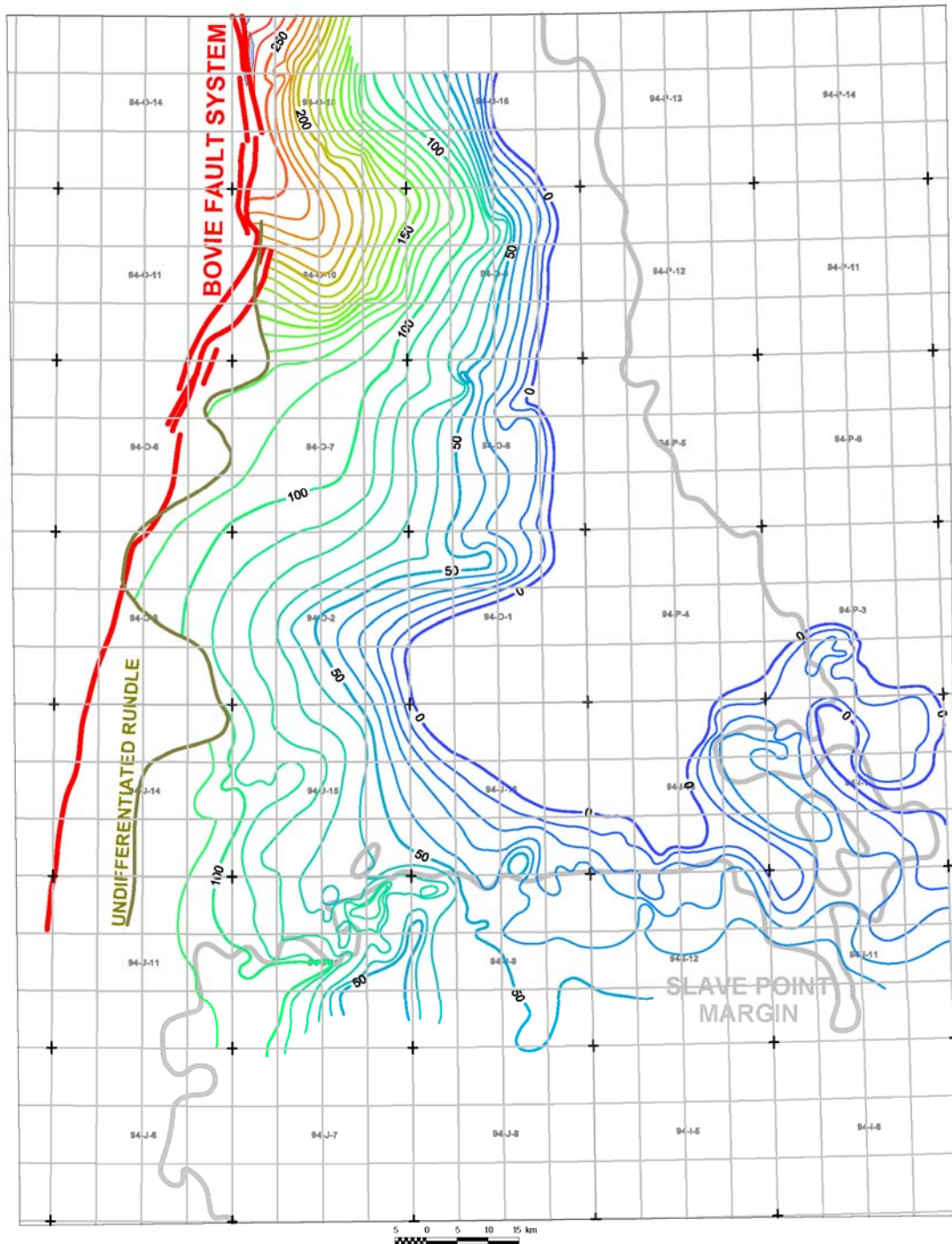
ISOPACH MIDDLE RUNDLE

- Subcrops east of HRB
- Cannot distinguish from remainder of Rundle and Debolt to west



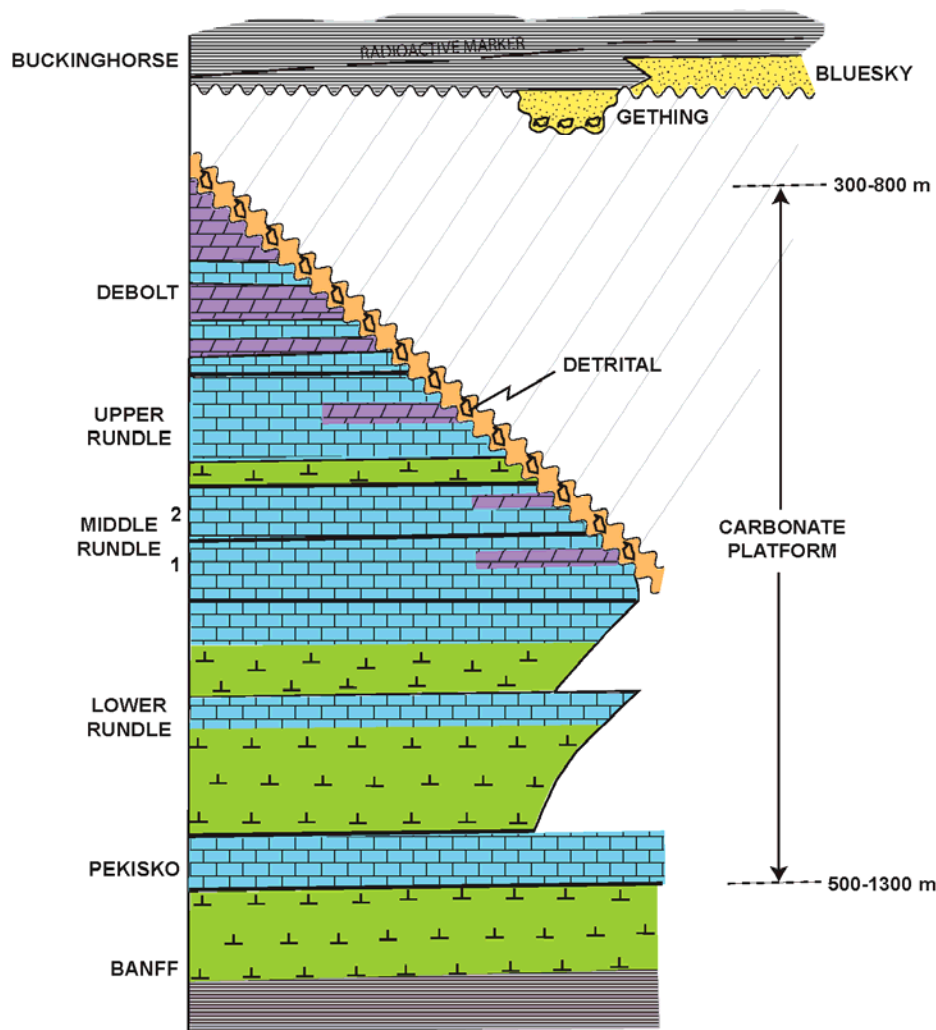
ISOPACH UPPER RUNDLE

- Subcrops at eastern margin of HRB
- Cannot distinguish from remainder of Rundle and Debolt to west



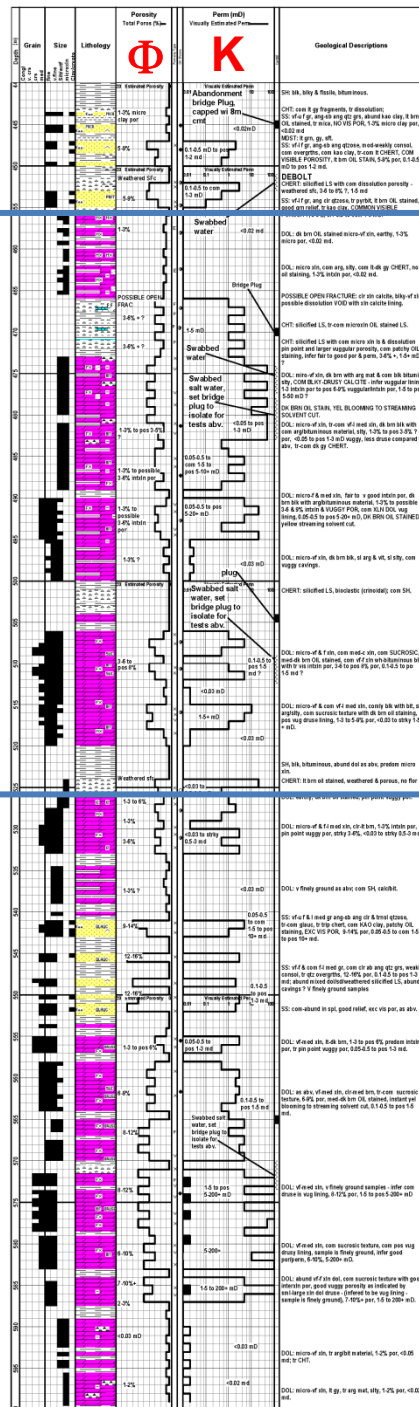
ISOPACH DEBOLT FORMATION

- Pre-Cretaceous valley incision influences subcrop edge
- Cannot distinguish from underlying Rundle to west



HORN RIVER BASIN PRIMARY RESERVOIR UNITS

- Best quality and most continuous reservoir is associated with the weathered interval capping the Mississippian carbonate platform, beneath the pre-Cretaceous unconformity
 - “Detrital zone”



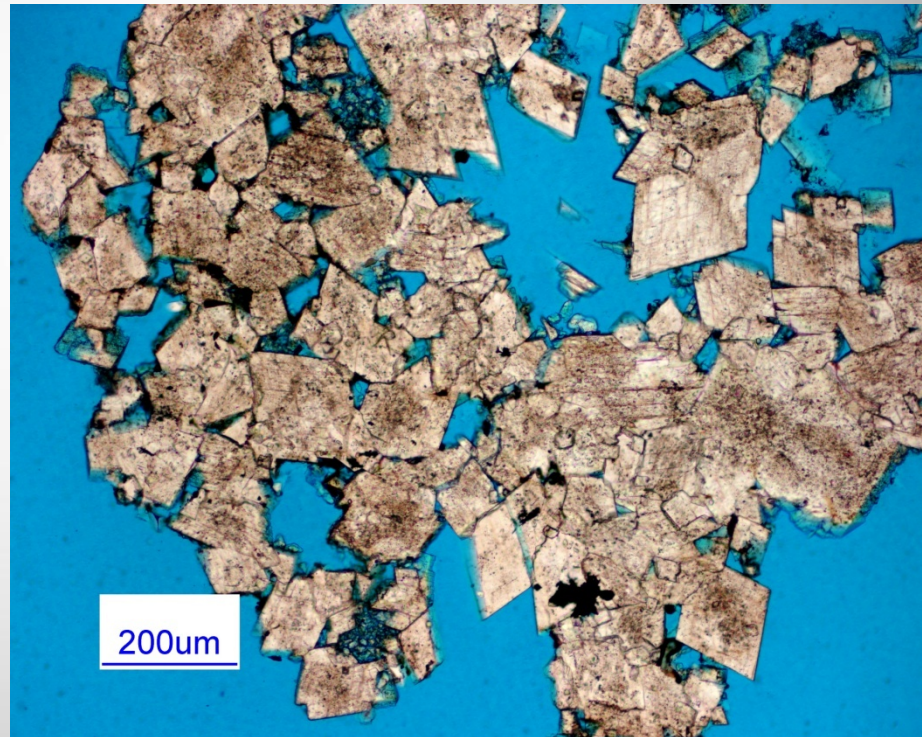
Debolt

Upper Rundle

25 m

DETRITAL ZONE

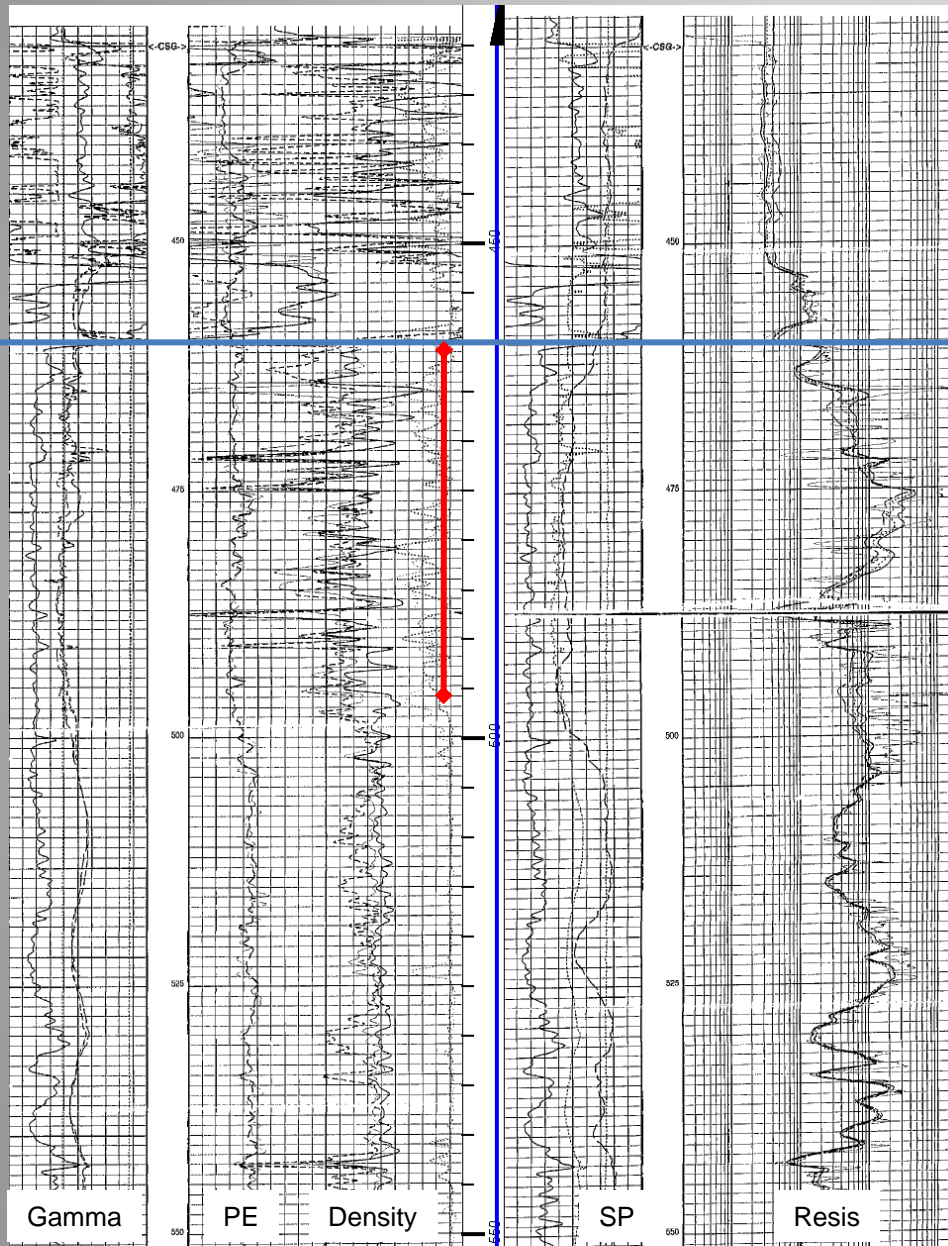
- Extensive and intensive dolomitization at pre-Cretaceous unconformity
- Poor core and sample recovery
- Poor log characterization – washed out



d-92-H / 94-O-9

DETRITAL ZONE

- Extensive and intensive dolomitization at pre-Cretaceous unconformity
- Poor core and sample recovery
- Poor log characterization – washed out



DETRITAL ZONE OUTCROP ANALOGUE

Madison Group, Northern Montana

Solution breccia, dolomitization, recrystallization



Regional fracturing
(Giant Springs, Great Falls)

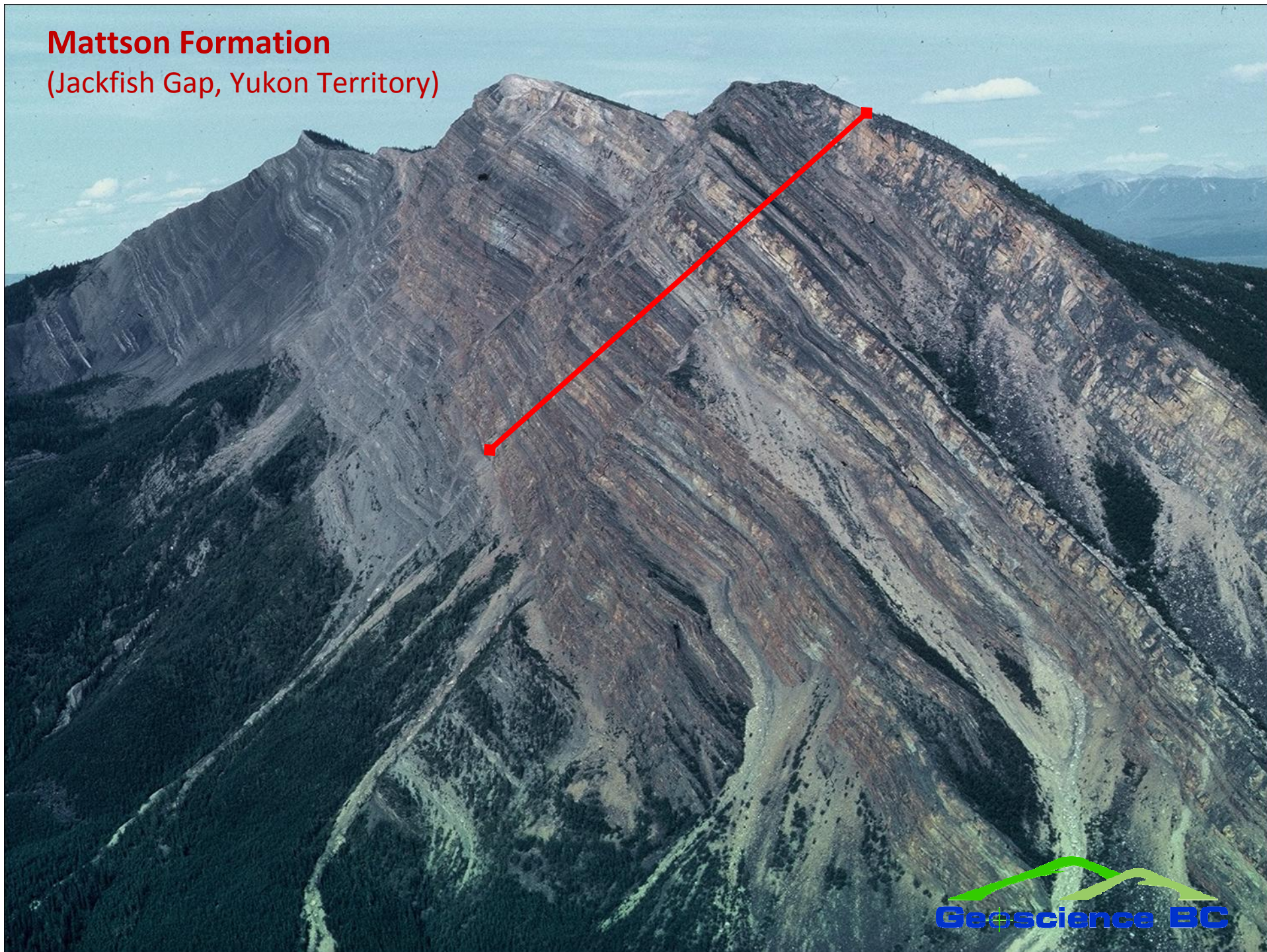


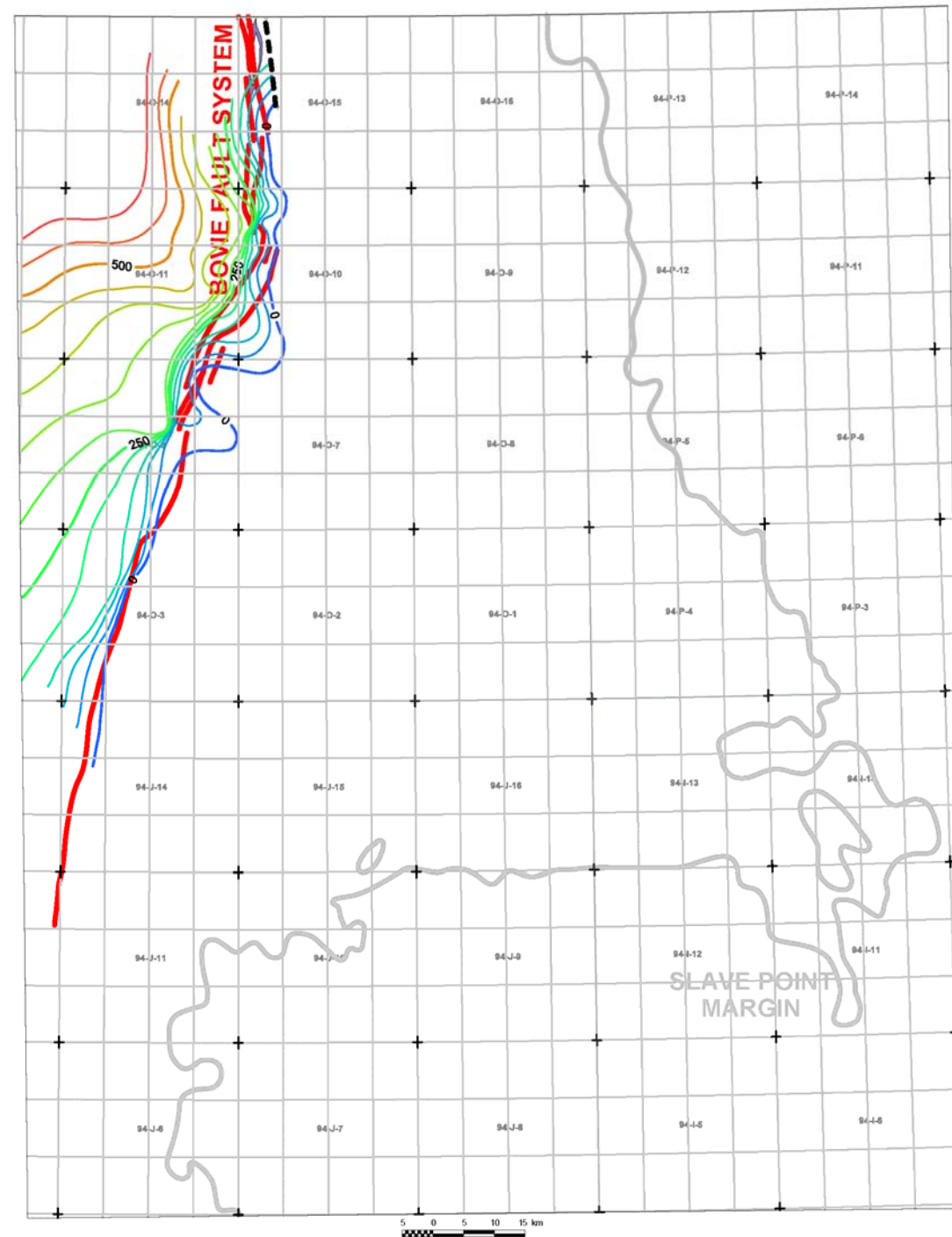


MATTSON FORMATION

- Stacked fluvial – deltaic sandstones
- Good primary reservoir quality
- Variably cemented by silica and carbonate; local degradation by bitumen
- Present only on western margin of HRB

Mattson Formation
(Jackfish Gap, Yukon Territory)





ISOPACH MATTSON FORMATION

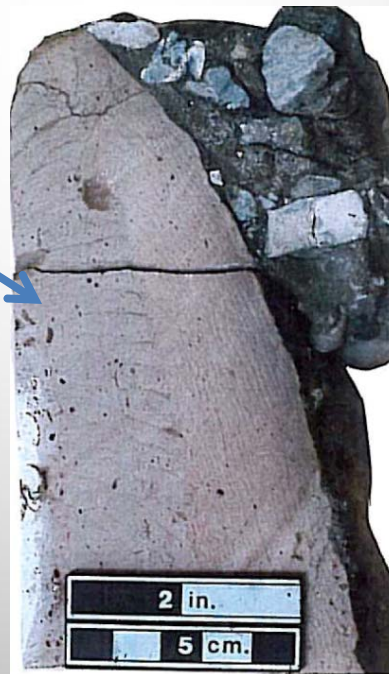
- Present only in Bovie Fault Zone, thickens rapidly westward
- May be aquifer target in extreme western part of shale gas area

GETHING FORMATION

- Fills south-north trending valley on eastern flank of HRB
 - incises eastern margin of Debolt
- Abundant poorly-sorted detritus
- Variable reservoir quality, but some good rock in most wells
- Hydrodynamic connection with Debolt



Debolt clast





BLUESKY FORMATION

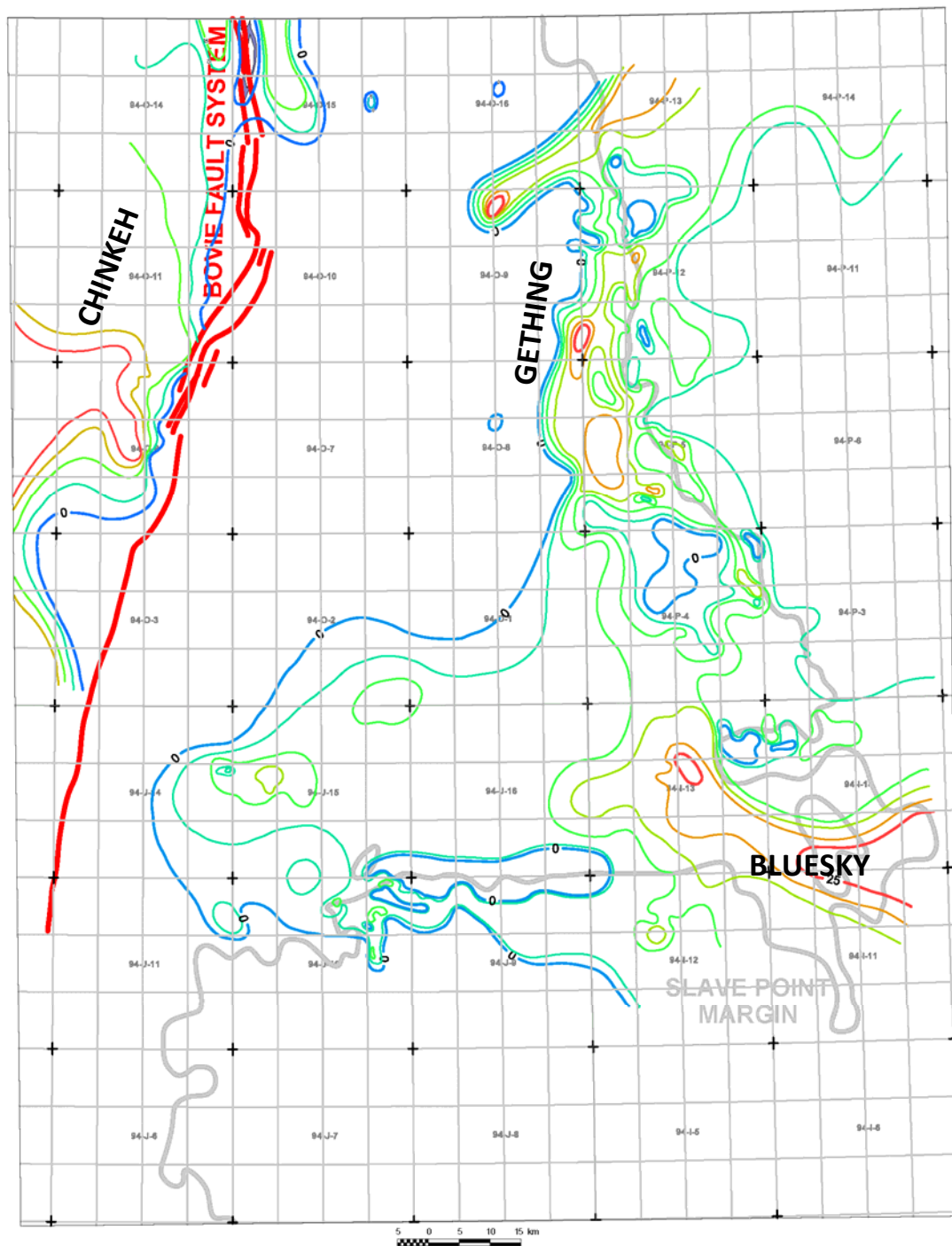
- West-east trending shoreface on southeastern flank of HRB
- Grades westward to offshore deposits
- Good reservoir quality only in southeast
- Unlikely to be an important aquifer – moderate quality, away from main gas shale target areas

Truncated *Rosselia* burrow



CHINKEH FORMATION

- Fluvial to marginal marine / shoreface
- Mapped throughout Liard Basin
 - found locally in far northwestern corner of HRB
- Generally modest reservoir quality
- Unlikely to be important aquifer – moderate quality, too far west
 - possibly local importance in NW 94-O-15, if reservoir volume is sufficient



ISOPACH CRETACEOUS SANDSTONES

- Gething valley fill to east
- Bluesky shoreface to southeast
- Chinkeh fluvial / deltaic to west (Liard Basin)

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT

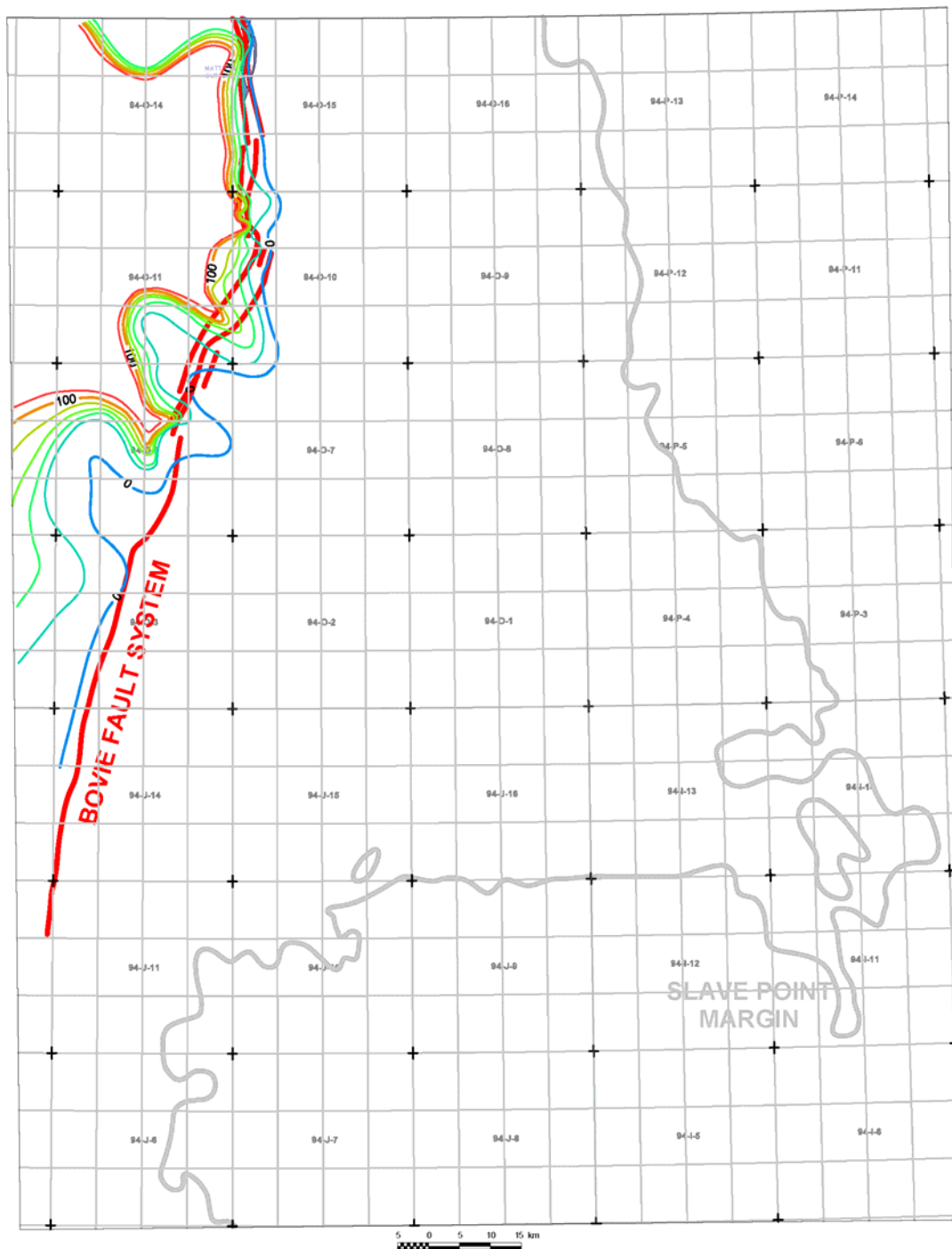
RESERVOIR ROCK SUMMARY

- Mississippian carbonate platform
 - Limited reservoir quality in shoaling-up cycles in middle to upper Rundle and Debolt
 - Local dolomitization / solution enhances reservoir quality in upper parts of cycles
 - Capping “detrital zone” exhibits widespread and generally good to excellent reservoir quality
- Mattson Formation
 - Variable but generally good reservoir quality
 - Thickens sharply westward from Bovie Fault Zone; absent in HRB
- Cretaceous sandstones
 - Gething valley fill (eastern flank) relatively thin, but has some good reservoir
 - Bluesky shoreface (southeast) – moderate reservoir quality, only locally developed
 - Chinkeh Formation (western flank) – moderate reservoir quality, possible local importance in far northwest

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT

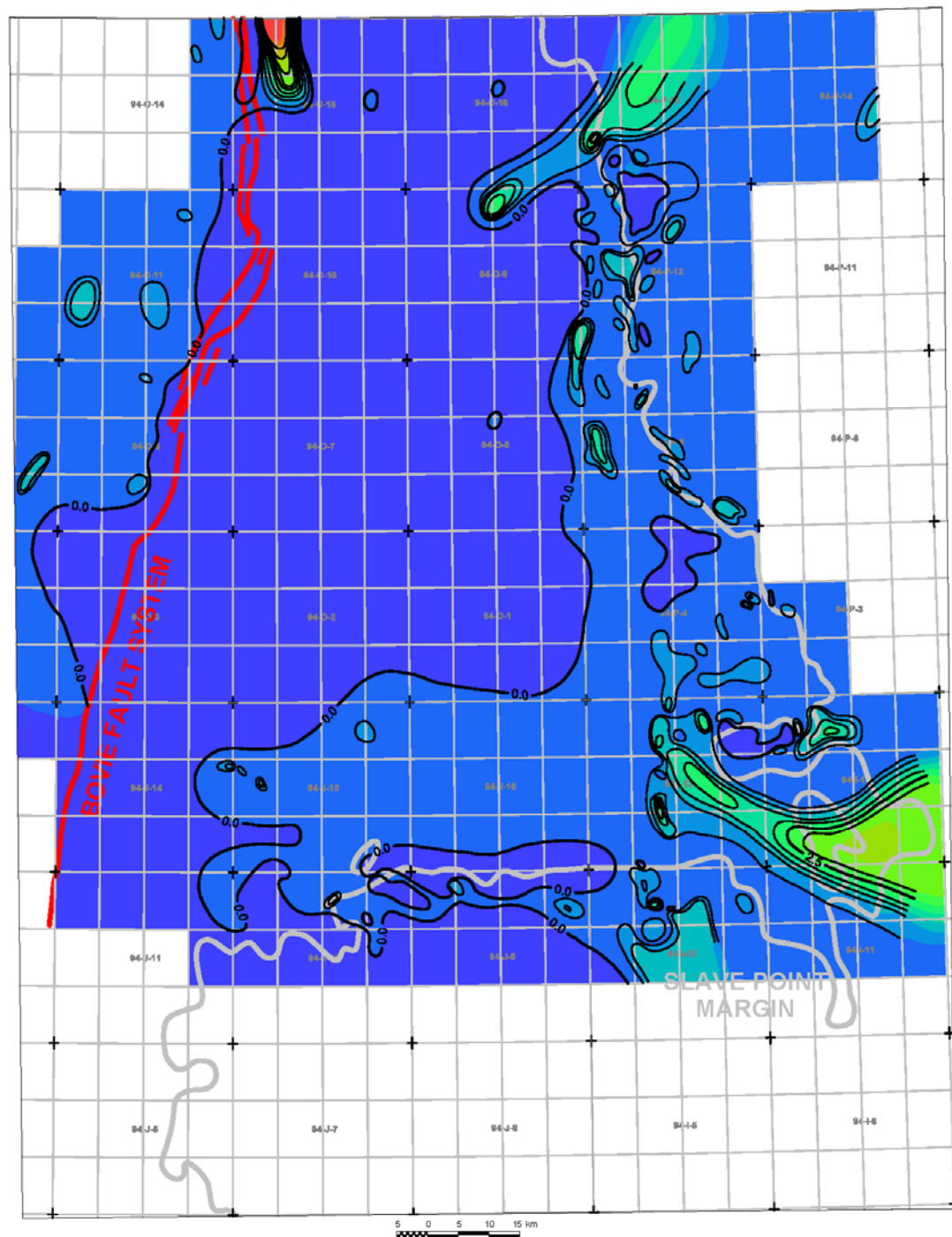
RESERVOIR QUALITY MAPPING

- Quantification of aquifer potential a product of reservoir thickness and quality: **porosity-thickness maps**
- Mattson and Cretaceous sandstones quantified using standard log porosity cutoffs
 - Mattson 6% Φ cutoff (generally fine-grained)
 - Cretaceous 3% Φ cutoff (coarser-grained)
- “Detrital” carbonates more difficult to quantify
 - Variable mineralogy, fracturing, and heterogeneity render porosity logs only qualitative indicators of reservoir quality
 - Classify reservoir as excellent / good / poor based on sample cuttings logs, well logs, and wellsite cuttings logs (approx. 3/6/9% Φ cutoffs)
 - Calculate Φ -h as:
 - Enhanced reservoir thickness (m) x reservoir quality porosity cutoff value



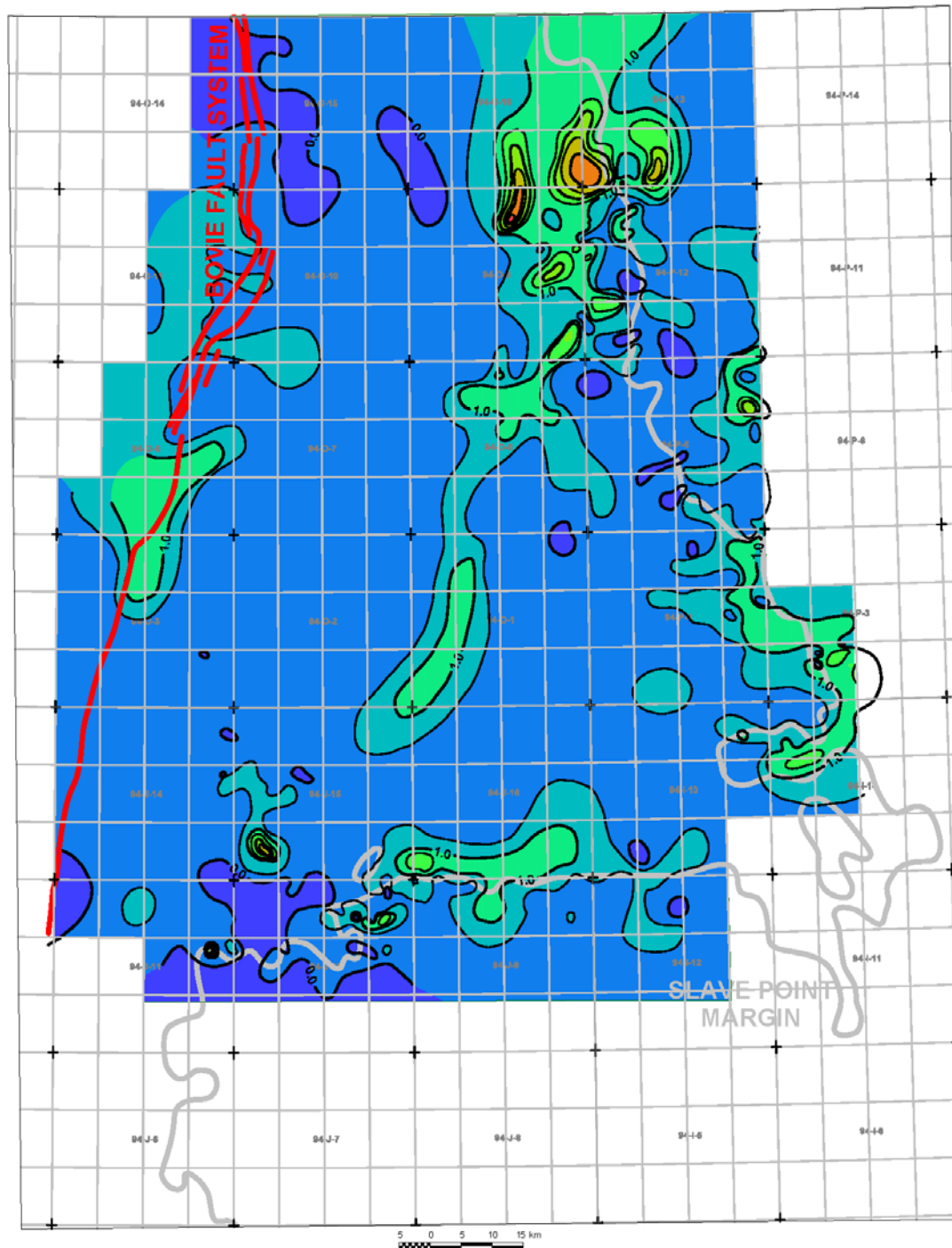
NET POROUS ISOPACH MATTSON FORMATION

- 6% Φ cutoff
- >100 metres of 6% (+) sst a few km west of HRB shale gas project areas, but none within current developments



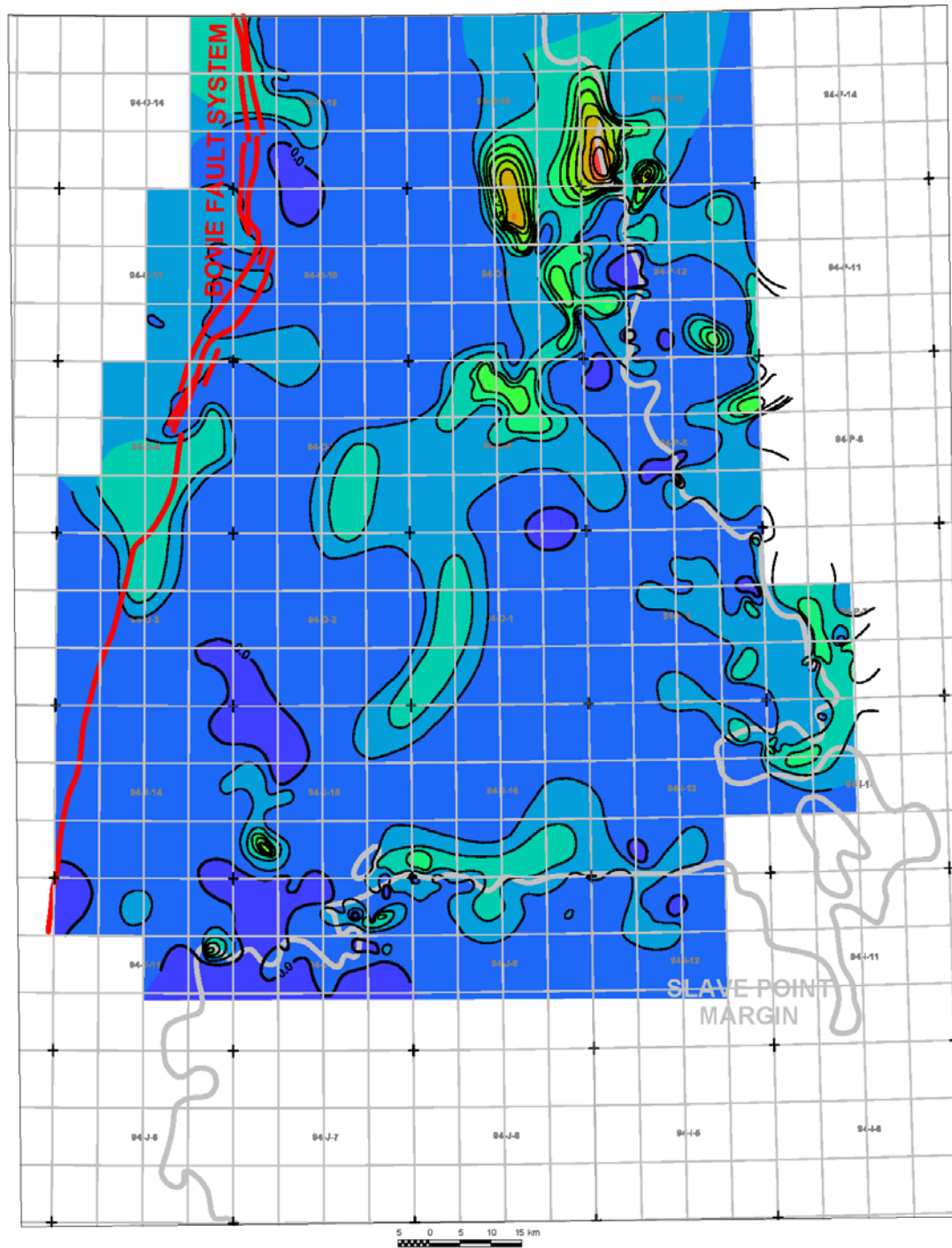
POROSITY-THICKNESS CRETACEOUS SANDSTONES

- 3% Φ cutoff
- Patchy reservoir in Gething valley
- High-porosity Bluesky in SE is in fine-grained rock with lower perms, and is southeast of most gas shale projects
- Lateral extent of high-quality Chinkeh in northwest is not clear, but may impact local gas shale projects



POROSITY - THICKNESS “DETRITAL ZONE”

- Major N-S fairway associated with Debolt subcrop edge and Gething valley incision
 - values range up to 4.0 Φ -m (>40 m of 9% Φ)
- Other thicks along eastern margin may be associated subcrop of particular units
- Does local structure assist in reservoir enhancement along southerly Slave Point margin and Bovie Fault Zone ?
- Almost no well control in western half of HRB



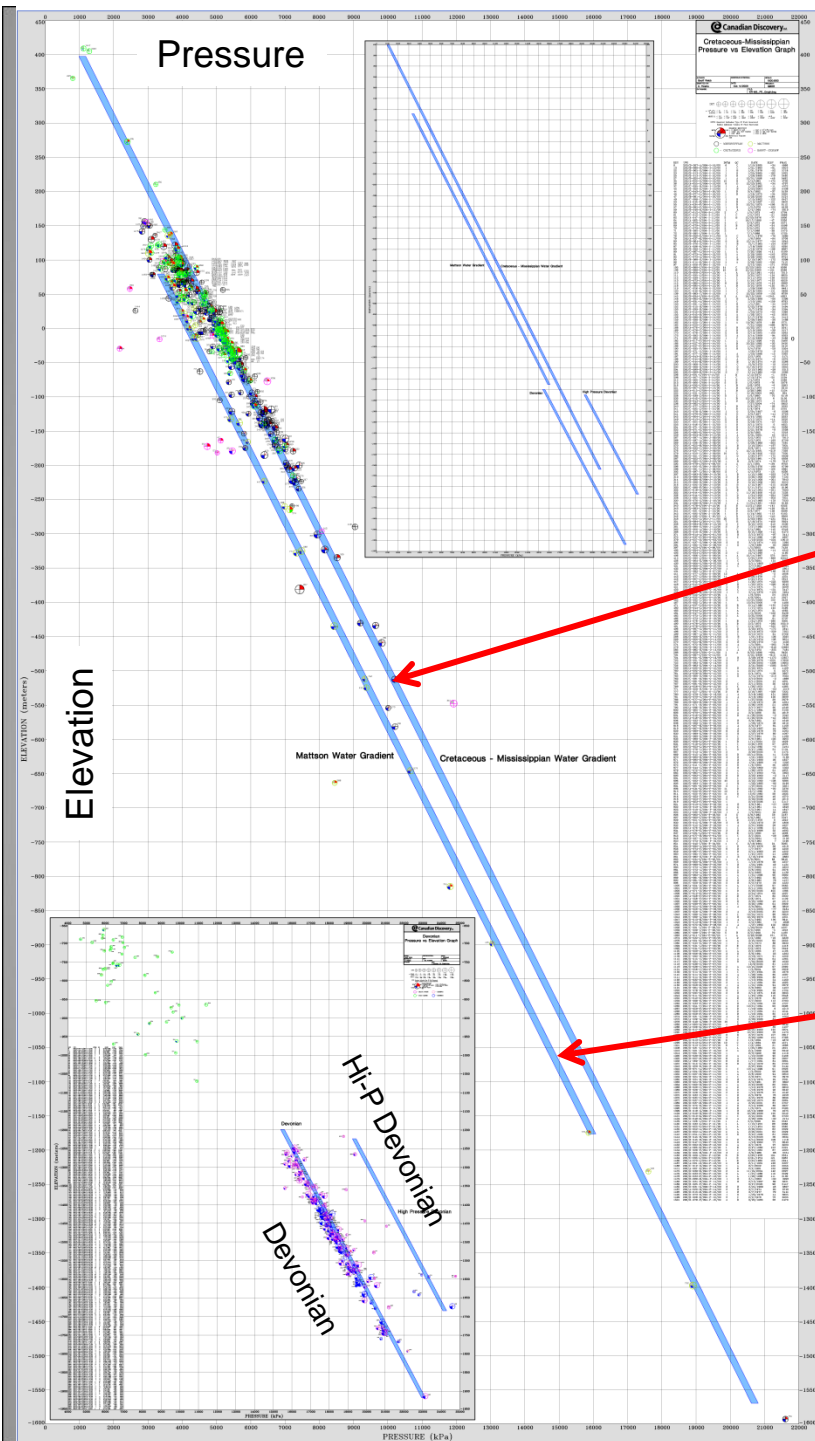
POROSITY - THICKNESS CARBONATE PLATFORM (Total enhanced reservoir)

- “Detrital” zone values dominate, but good reservoir in lower zones is locally important

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT

HYDROGEOLOGY

- Canadian Discovery Ltd. compiled and analyzed DST and pumping / injection data
 - Most available data is from outside HRB, and is used to provide regional context
 - Supplemental test data collection within HRB, from new wells drilled by HRBPG members, was coordinated and partly financed by Geoscience BC
- Created hydrogeological analysis for HRB aquifers, tied to stratigraphy developed by Petrel Robertson
 - Hydrostratigraphic units – P/E plots, hydraulic head maps
 - Fluid chemistry
 - Reservoir injectivity and flow capacity



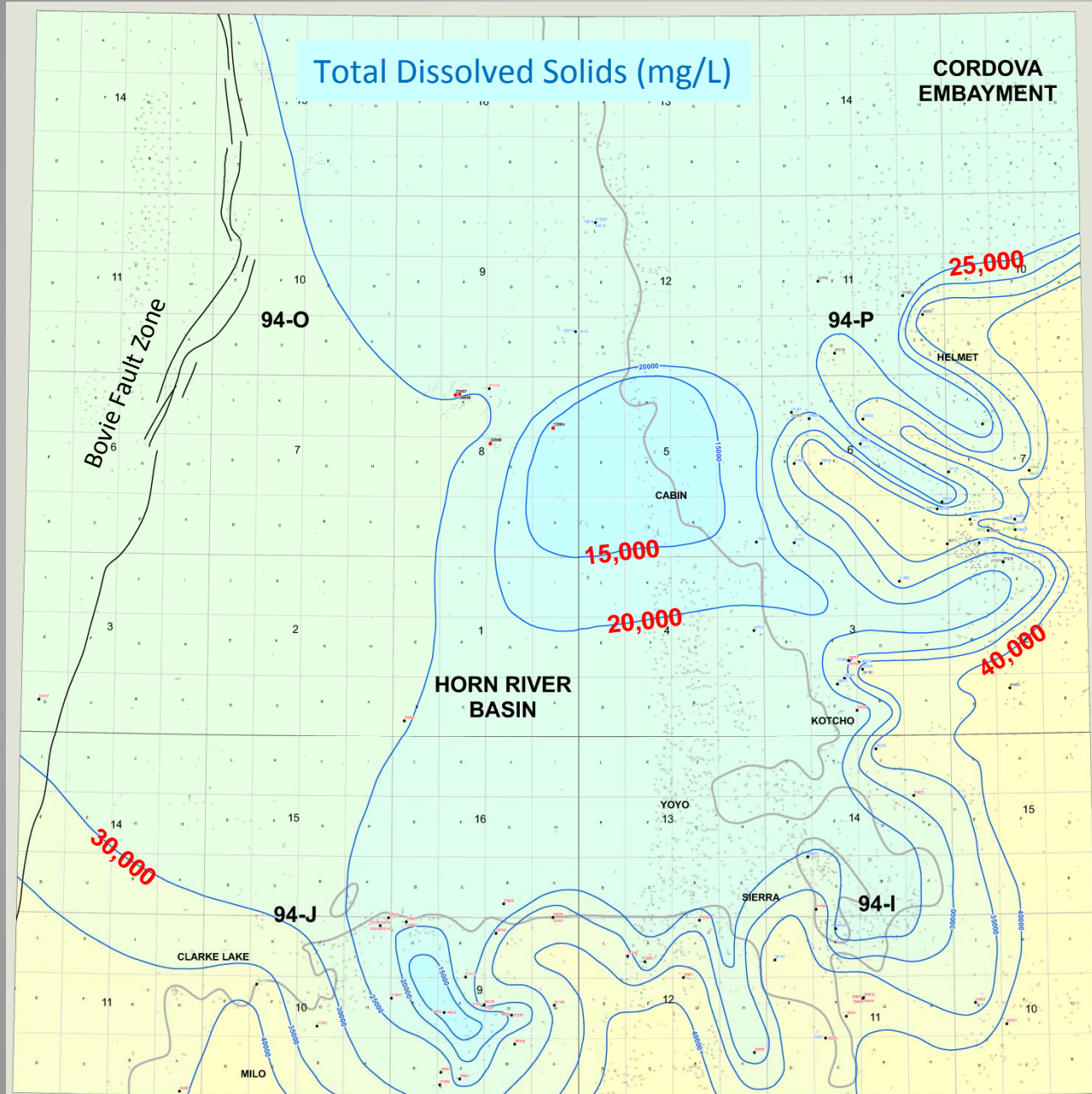
Pressure – Elevation Plots

Cretaceous – Lower Rundle Hydrostratigraphic Unit

- Bounded by Cretaceous Buckinghorse Shale and Banff Fm
- Single, well-defined water gradient
 - normally- to slightly under-pressured
- Regional extent – much larger than Horn River Basin
 - numerous associated gas and oil pools

Mattson Formation

- Water gradient distinct from Cretaceous – Rundle
- Insufficient data to define upper and lower boundaries of hydrostratigraphic unit

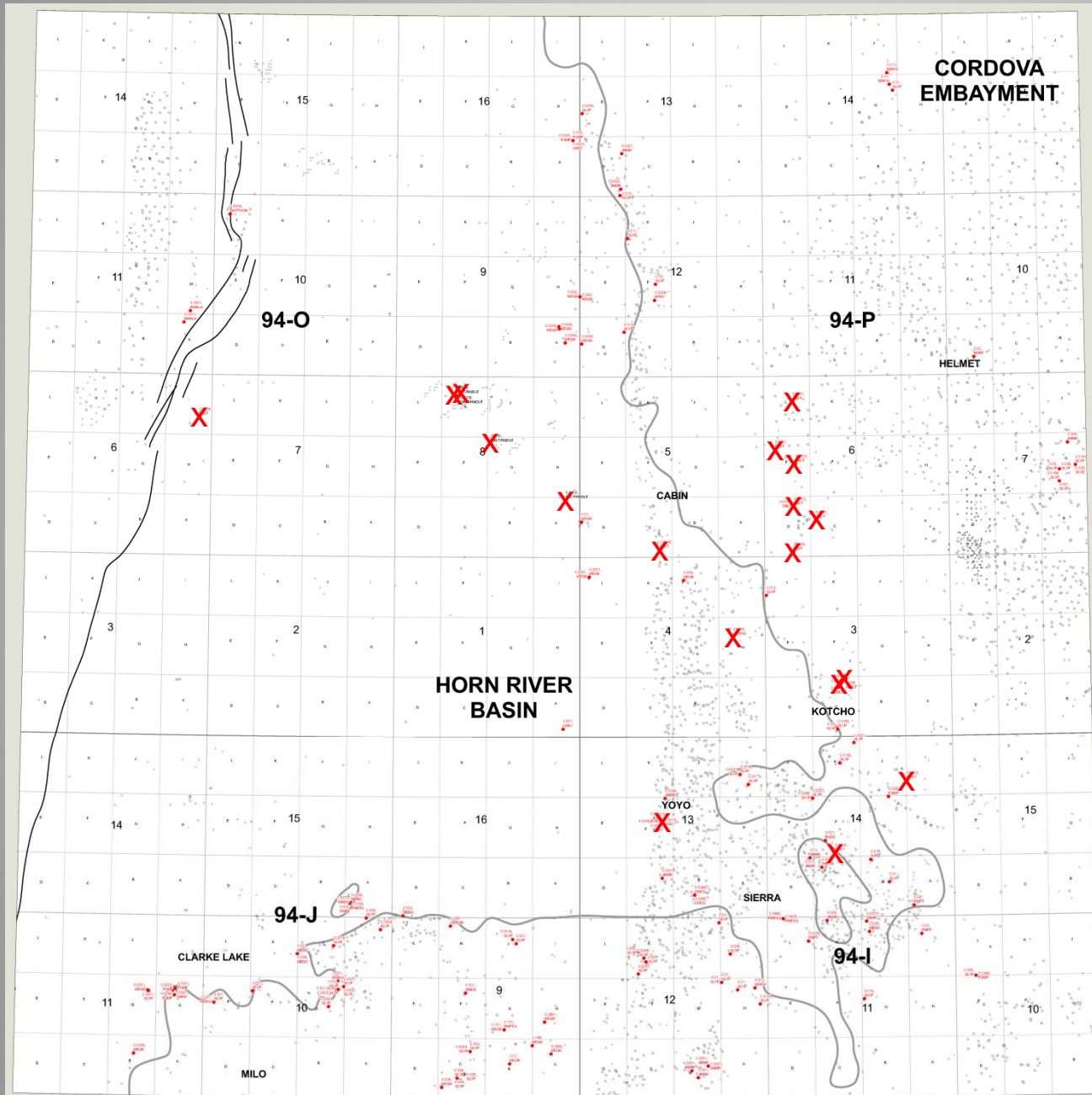


Cretaceous – Rundle Hydrostratigraphic Unit

Water Salinity

Formation water TDS
15,000 – 40,000 mg/l

- Much too saline to be potable, but still OK for use as completion fluid
- Values similar across entire vertical section



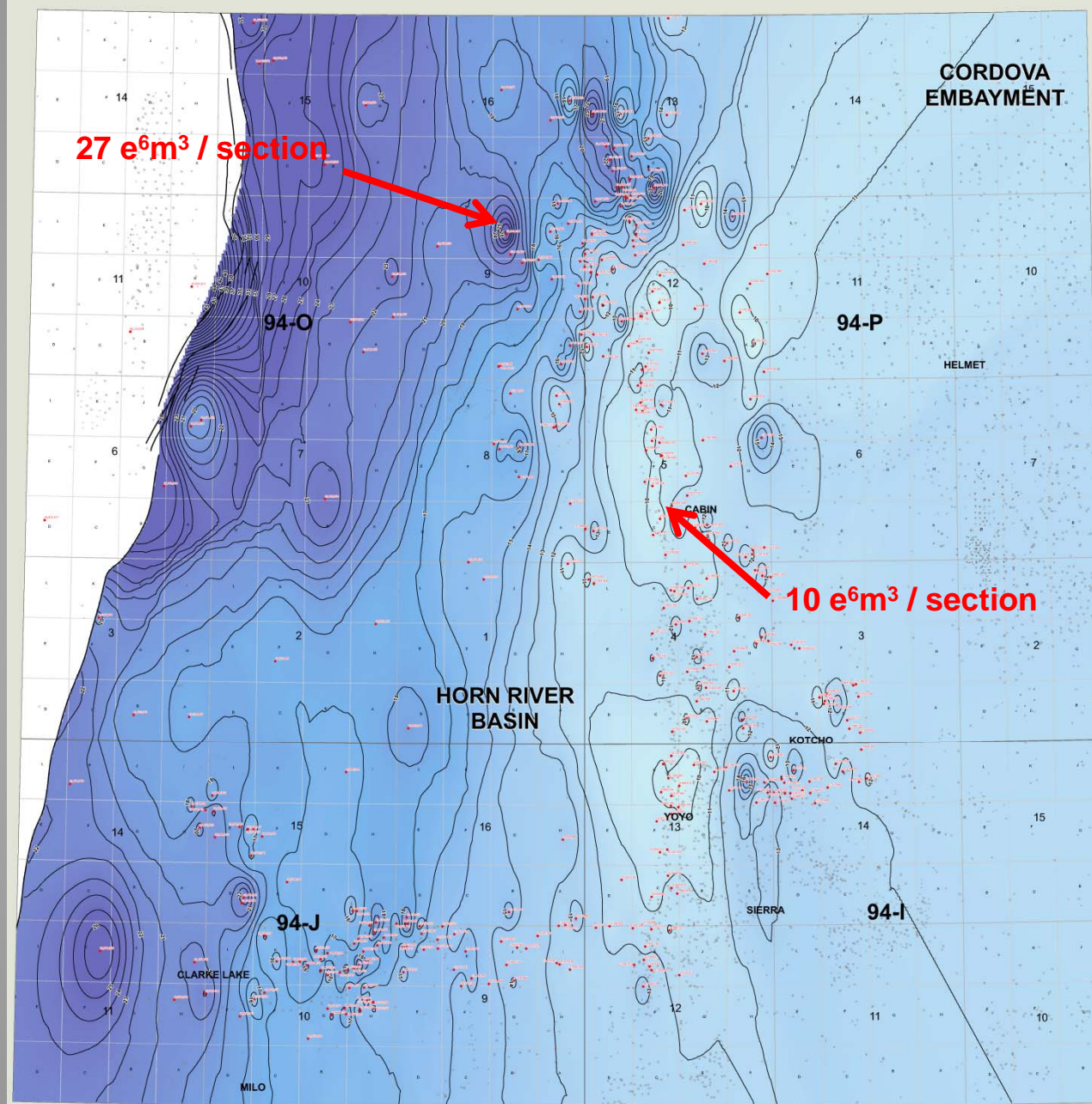
Cretaceous – Rundle Hydrostratigraphic Unit

H₂S Concentration

Very low H₂S concentrations
in Rundle / Debolt

- Most <0.001 mole %
- Highest 0.006 mole %
(6000 ppm)

X – H₂S in Cret / Miss



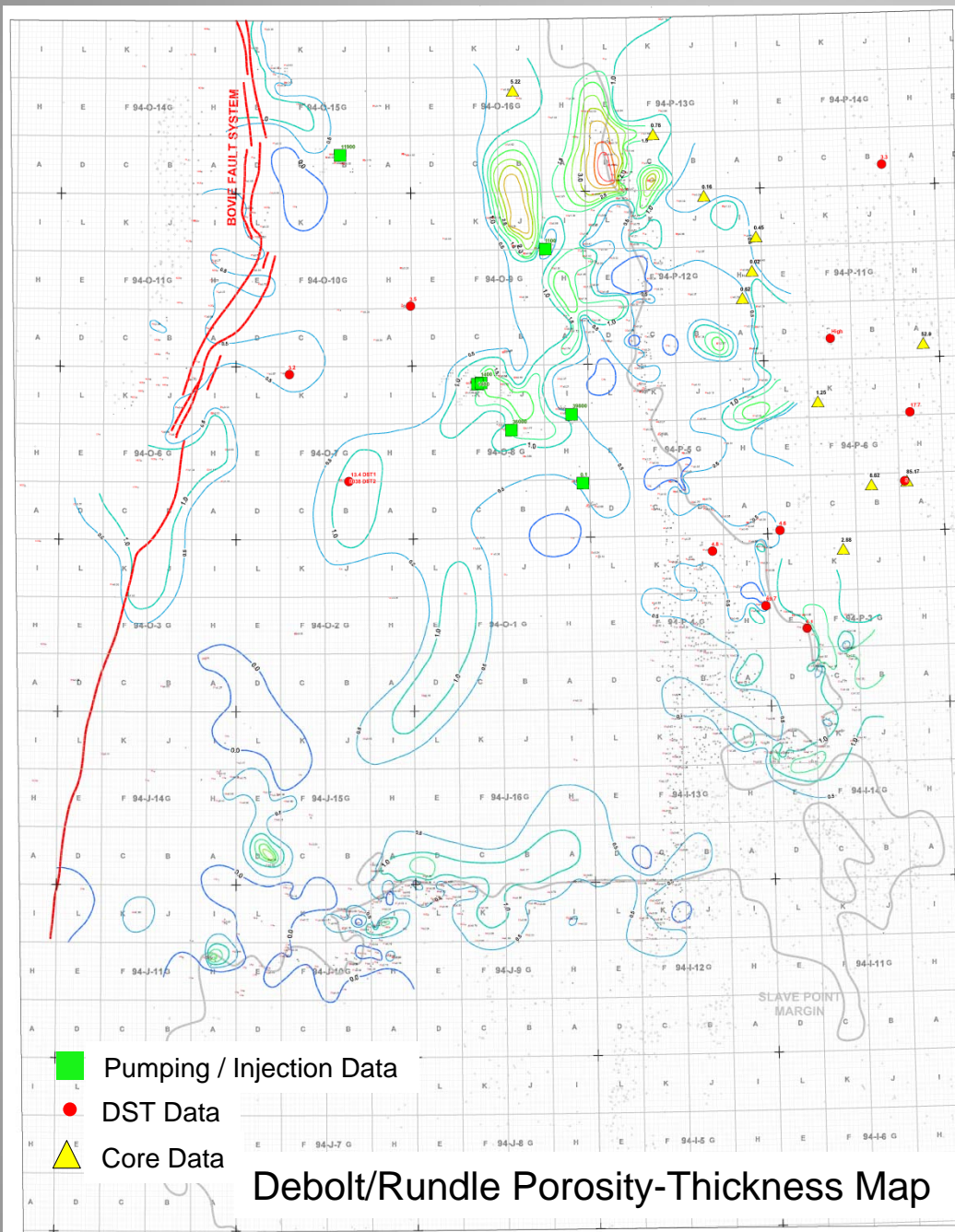
Debolt – Rundle Aquifer

Water Volumes in Place

Assumptions:

- Average porosity = 2%
- “Enhanced” porosity = 9%

Total water volume – 95 e⁹m³
- 15 e⁹m³ in “enhanced” rock



Debolt – Rundle Aquifer

Permeability

P/I tests all located where
“enhanced” reservoir exists

- All except one show $K > 1000$ mD
- Maximum 39,800 mD

Core and DST results show
K < 10 mD in regional strata

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT CONCLUSIONS (1)

- Stratigraphic analysis shows three subsurface units with aquifer potential:
 - Mississippian carbonate platform
 - Mattson Formation
 - Cretaceous sandstones
- Best quality and most continuous reservoir in “detrital” unit capping Mississippian carbonates, particularly associated with Debolt subcrop edge (and pre-Gething valley incision)
 - Very little well control in western half of HRB – is this unit more widespread?
 - Existing data support only semi-quantitative reservoir quality assessment
- Local Φ -h thicks in west associated with Mattson and Chinkeh

HORN RIVER BASIN AQUIFER CHARACTERIZATION PROJECT CONCLUSIONS (2)

- Mississippian carbonates and Cretaceous sands occur within a single hydrostratigraphic unit
 - Mattson sands geographically separated, on a different water gradient
- Waters are saline, but suitable for use as completion fluid
 - Low concentrations of sour gas seen in Mississippian waters – requires further assessment
- Extremely high permeabilities occur in Mississippian “detrital” unit
 - Flow/injectivity tests, DST’s, cuttings samples, well logs
 - Mappable along Φ -h fairways
- Relatively limited reservoir potential in sandstone aquifers
 - Potential local “sweet spots” in Mattson and Chinkeh



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