

Two Medicine Cut Bank Sand Unit (TMCBSU) Phase 3: Geological Mapping

Arkanova Energy Corporation

Operator: Provident Energy Associates of Montana, LLC

Kim Hemsley, Jennifer Zinn

G&G Team, DCS NGC

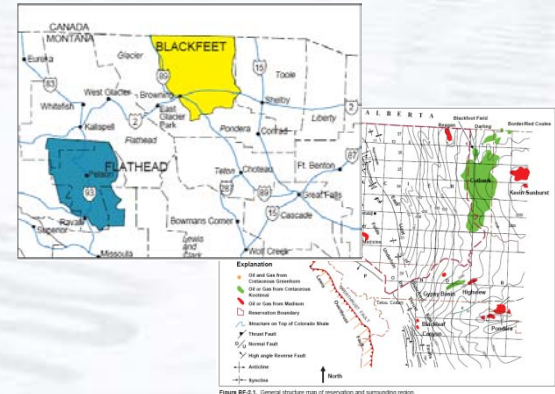
March 2, 2010



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Overview

- TMCBSU Phase 3 – Geological Mapping
 - Review
- Discussion
 - Next Steps



Phase 3: Geological Mapping

■ Objective

- Update 1972 TMCBSU field maps
- Reliable structure, isopach and pay maps for well planning
- Geological model in Petrel for reservoir characterization and field development planning

■ Approach

- Acquire and digitize logs from available wells with raster logs (278) in the TMCBSU and immediate offset wells
- Construct geological model for TMCBSU field project
- Correlate and Map Upper and Lower Cut Bank Sand units



Regional Geology

*Reference: BLM Report 1996

- Lower Cretaceous Sandstone Play in NW Montana
- Monocline situated on the west side of the Sweetgrass Arch
- Cut Bank, largest oilfield, discovered in 1920's
- Lower Cretaceous continental fluvial deposition, sediment transport from west to East and NE
- Cut Bank Fm. has two main sand intervals, productive from Lower oil bearing sand

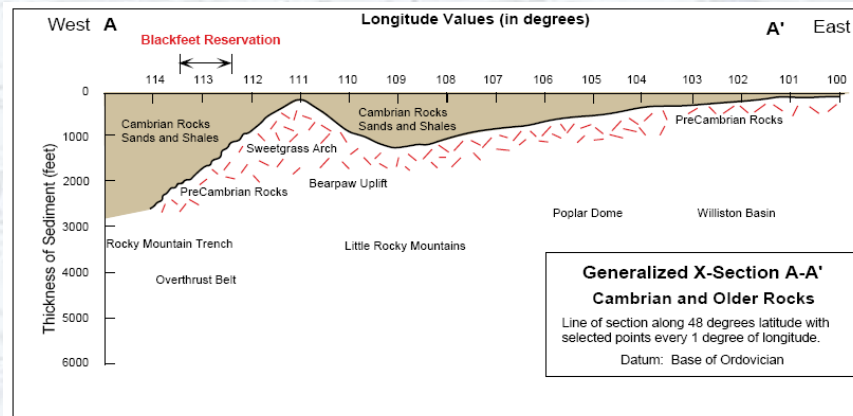


Figure BF-4.1. Generalized time slice cross-section of Cambrian paleo-topography along line of section A-A*.

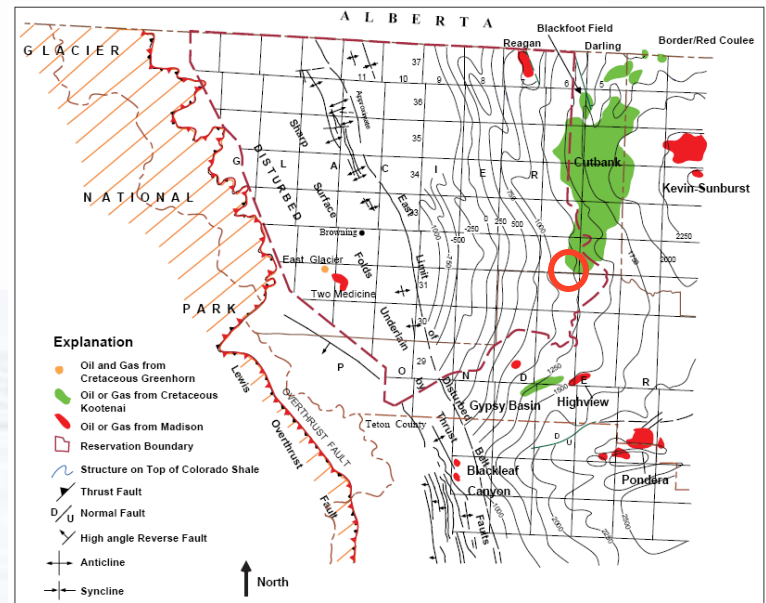


Figure BF-2.1. General structure map of reservation and surrounding region.

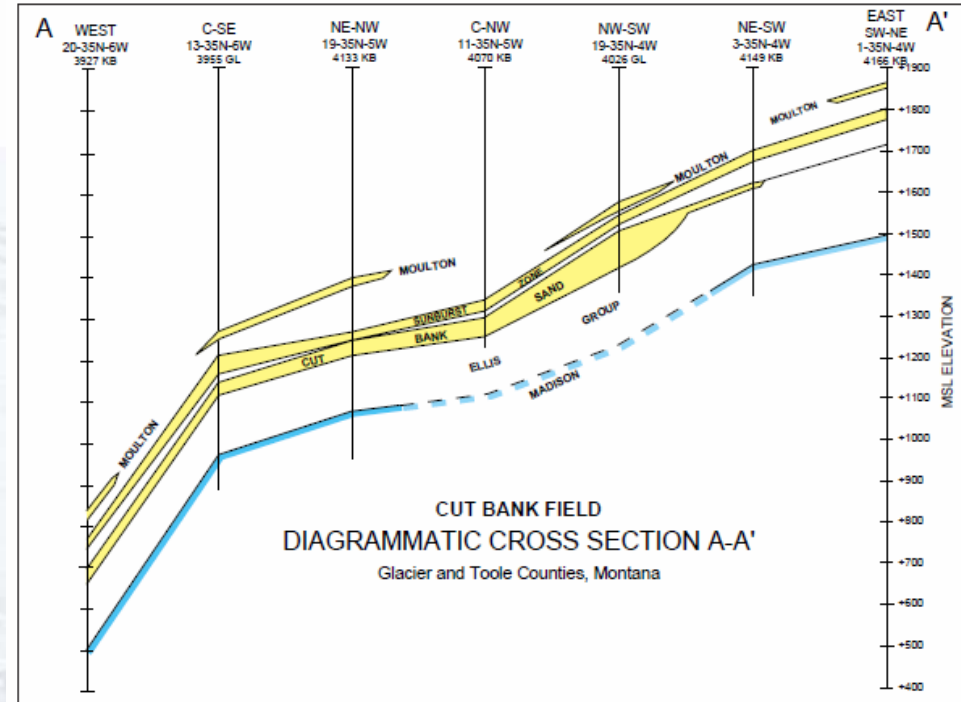
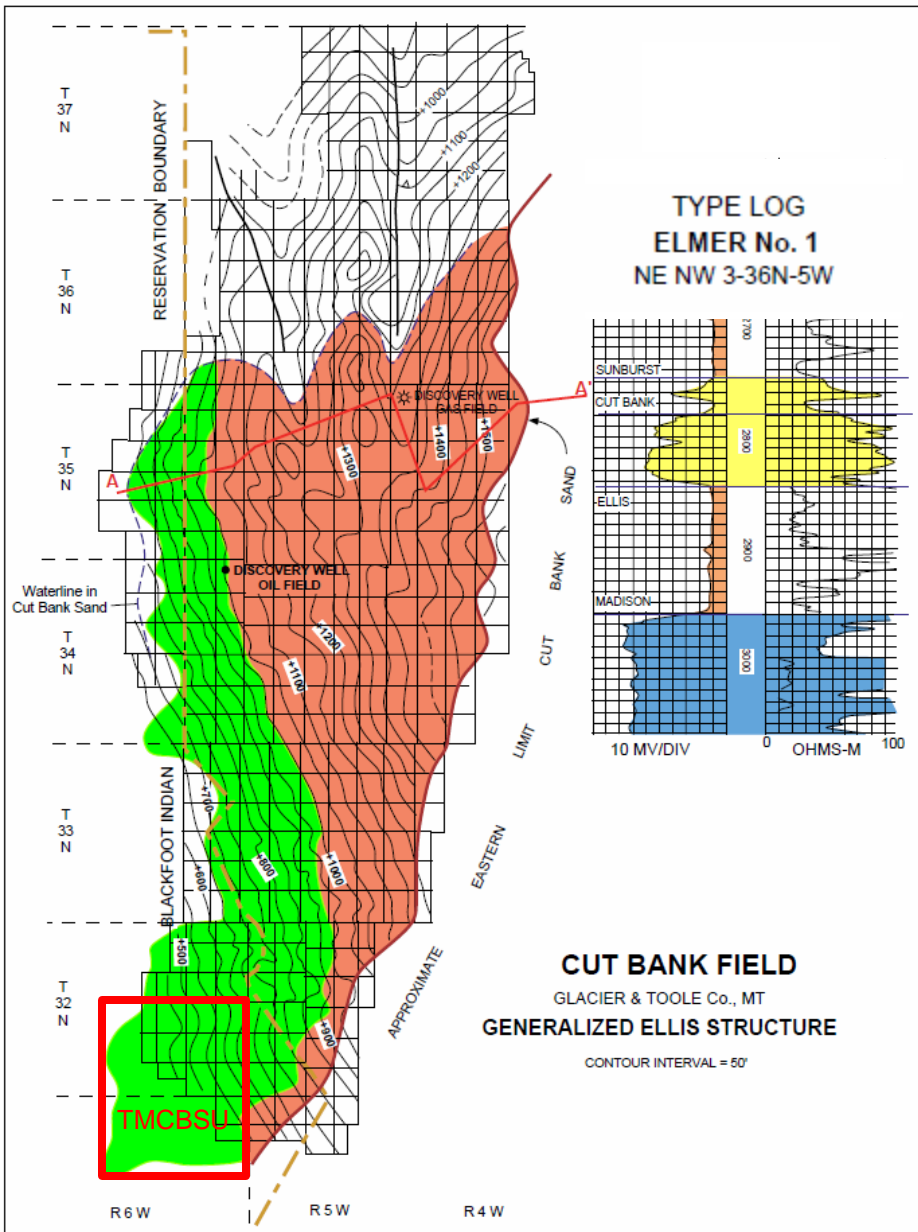
PRODUCING HORIZON LEGEND							
ERA	SYSTEM	SERIES	COLOR CODE	WILLISTON BASIN	POWDER RIVER BASIN	WESTERN WYOMING SOUTHERN MONTANA	WESTERN & NORTHERN MONTANA
CENOZOIC	TERTIARY			Fort Union	White River Wasatch Fort Union	Green River Wind River Wasatch Fort Union	Fort Union
MESOZOIC	CRETACEOUS	UPPER		Fox Hills Judith River Eagle Niobrara Greenhorn	Lance Teckla Mesaverde Teapot Parkman Sussex Shannon Niobrara Frontier	Fox Hills Mesaverde Cody Shannon Niobrara Frontier	Hill Creek Judith River Glaagat Eagle Telegraph Creek Niobrara Greenhorn Frontier
		LOWER		Dakota Group	Mowry Muddy Dakota Fall River Lakota	Mowry Muddy Bear River Dakota Cloverly	Bearpaw Kootenai Cat Creek Moulton Sunburst Cut Bank
JURASSIC				Morrison Ella Group Swift Reardon Piper Nasnon	Morrison Sundance Canyon Springs Gypsum Spring	Gannet Morrison Sundance Stump-Preuss Twin Creek Nugget	Morrison Ella Group Swift Reardon Sawtooth



Two Medicine Cut Bank Sand Unit (TMCBSU)



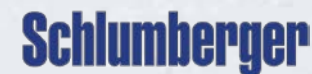
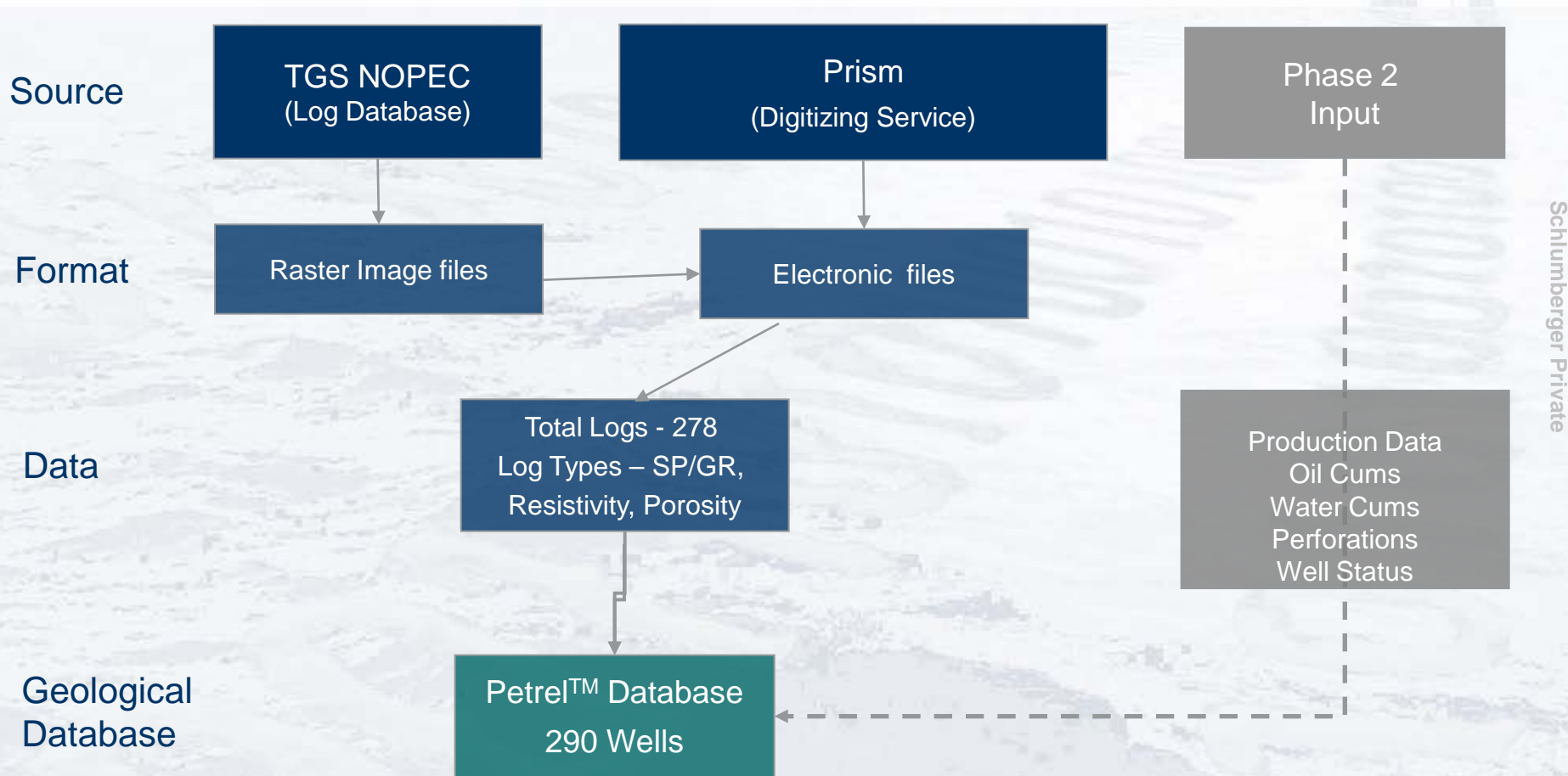
Regional Structure



Regional Dip to west
Gradient ~100 ft/mile

k Sand Unit (TMCBSU)

Phase 3: Workflow



Data Acquisition in Phase 3

278 Wells with log curves (SP, Gamma, Resistivity)
in the project

228 Wells with digitized logs in TMCBSU

50 Wells with digitized logs outside TMCBSU

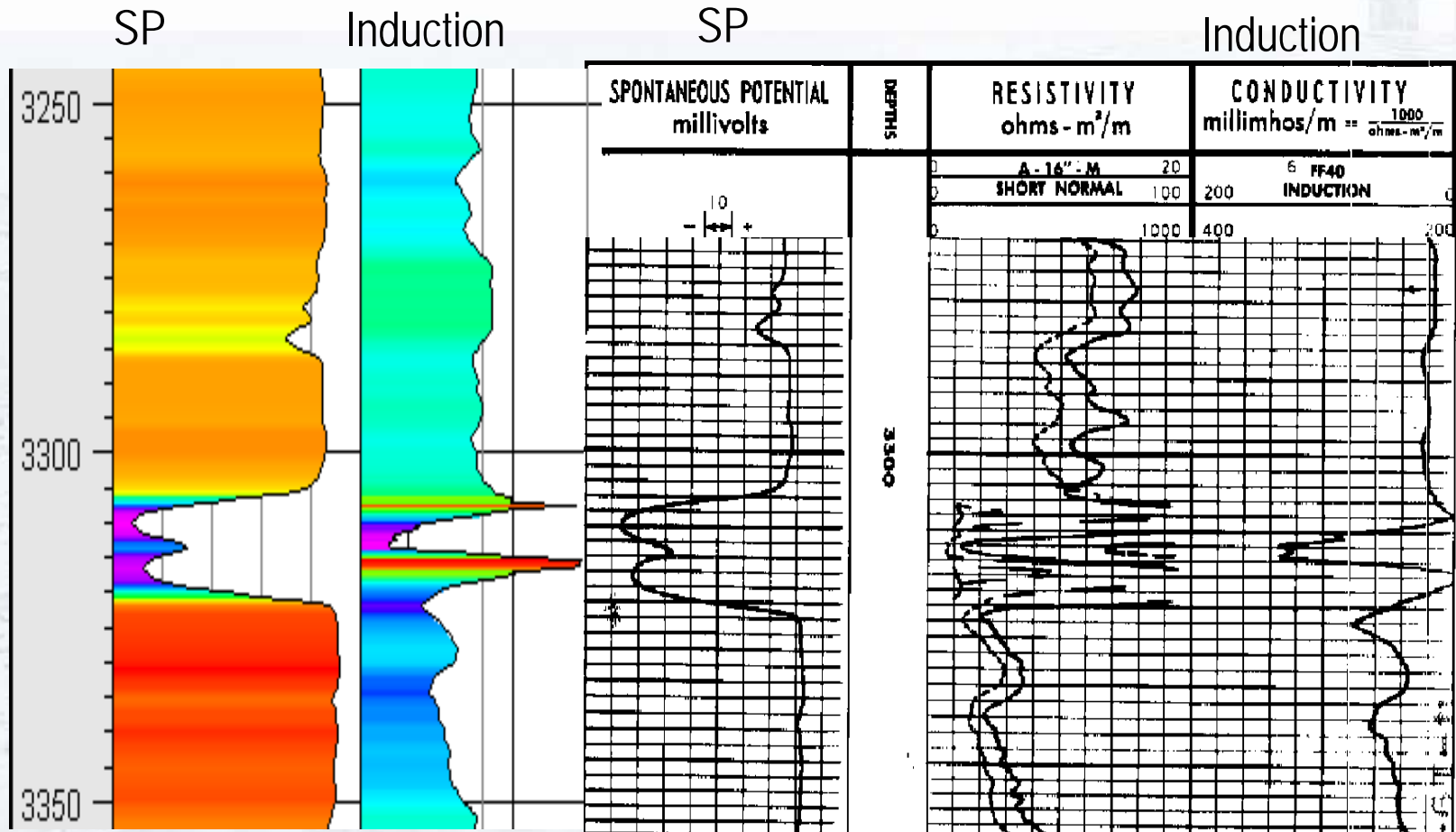
71 Wells with porosity logs

43 Wells with porosity curves in TMCBSU



QC - Raster Image to Digitized Log

25035050240000



Digitized Logs

Raster Image



Two Medicine Cut Bank Sand Unit (TMCBSU)

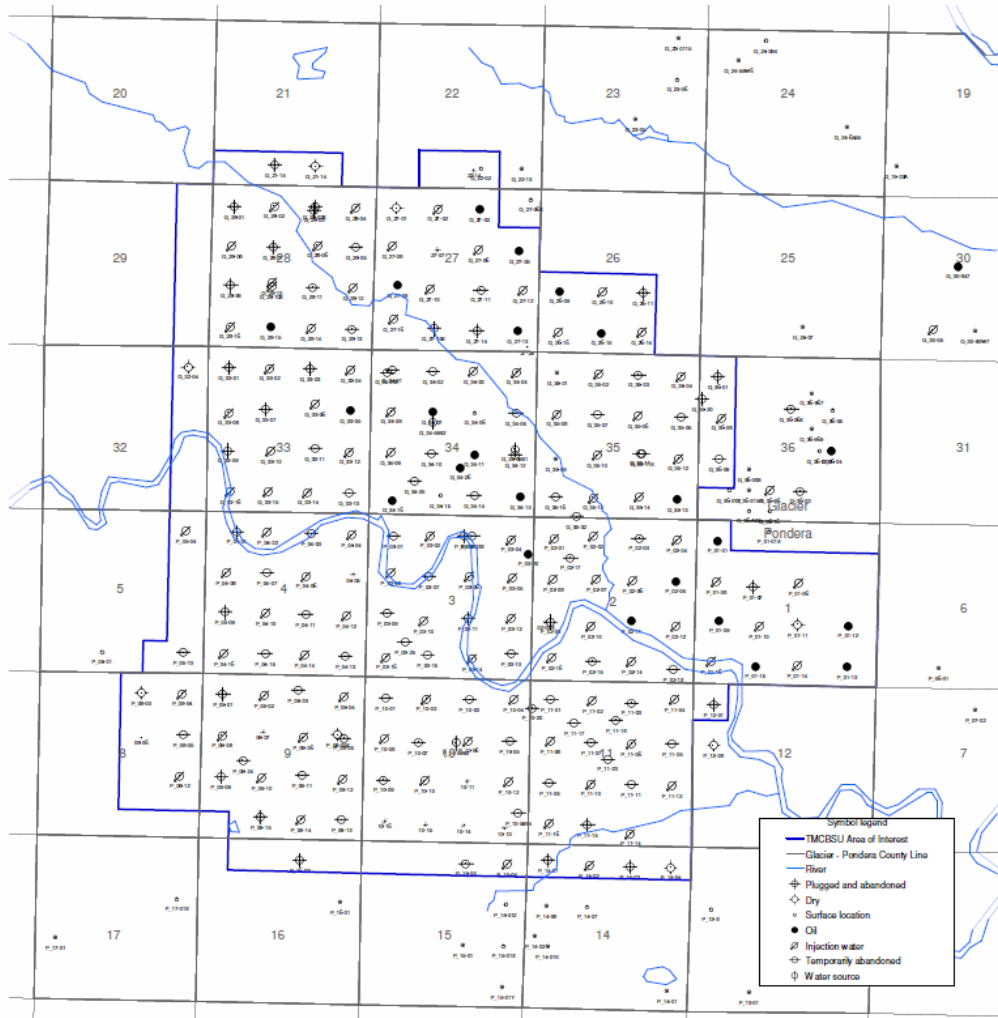




Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
BASEMAP- All Wells



Petrel™ Geological Project Basemap



278 Wells with digitized logs

Symbol legend

- █ TMCBSU Area of Interest
- Glacier - Pondera County Line
- River
- ⊕ Plugged and abandoned
- ⊖ Dry
- Surface location
- Oil
- ⊗ Injection water
- ⊖ Temporarily abandoned
- ⊕ Water source



BASEMAP	
Block	Segment
T-112500	005
Acct#	Location
407m	140400m
Company	Date
Schlumberger	02/22/2010

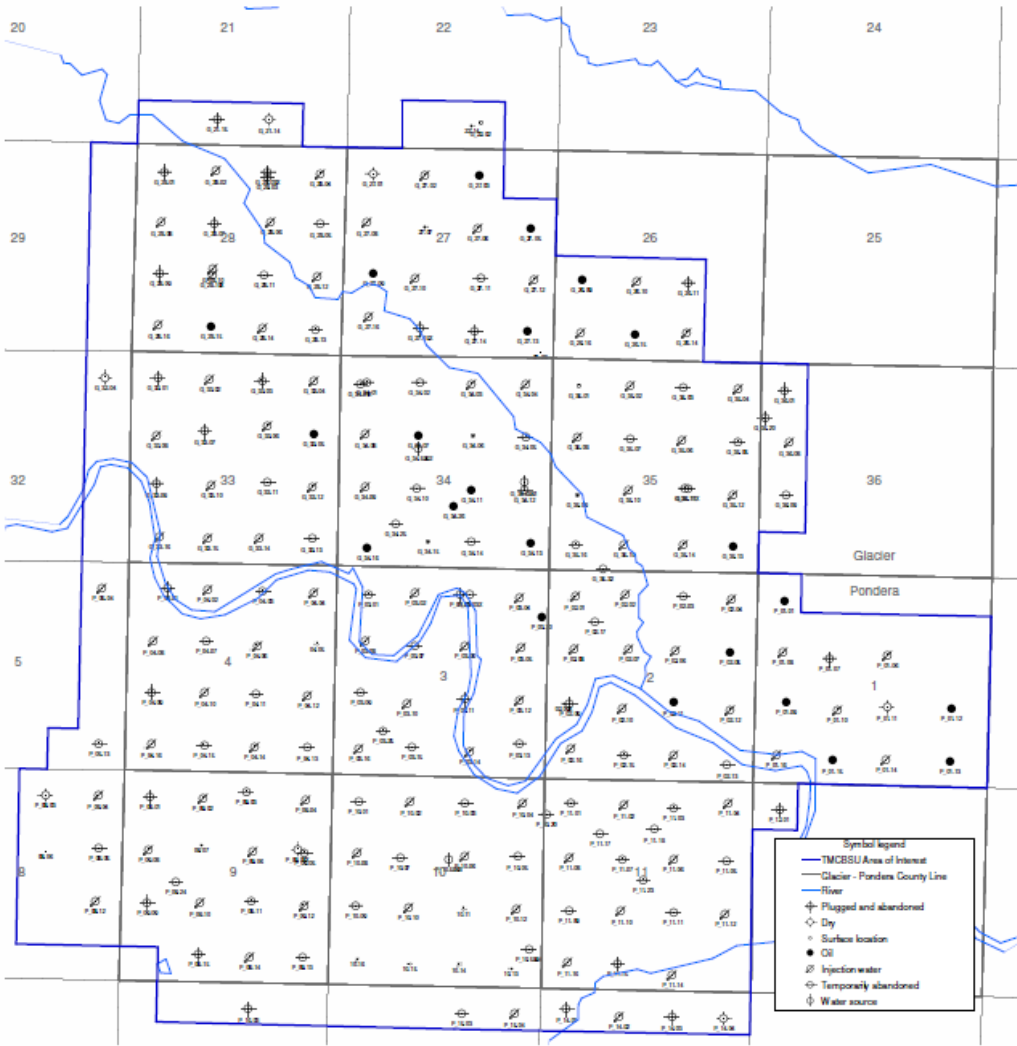


(MCBSU)





Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
BASEMAP



BASEMAP	
Scale	Segment
1:5000	DGS
Author	Location
JPH	Glacier
Company	Date
Schlumberger	02/2010



TMCBSU Basemap

CUT BANK Formation : 233 Wells

22 Active Producers

66 SI or TA Producers

31 P&A Producers

104 P&A Injectors

9 Dry Wellbores

1 Water Supply (5992)

MADISON Formation: 3 Wells

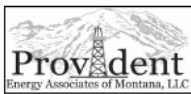
1 SI Producer: 5994

2 Disposal Wells: 5991 & 5993

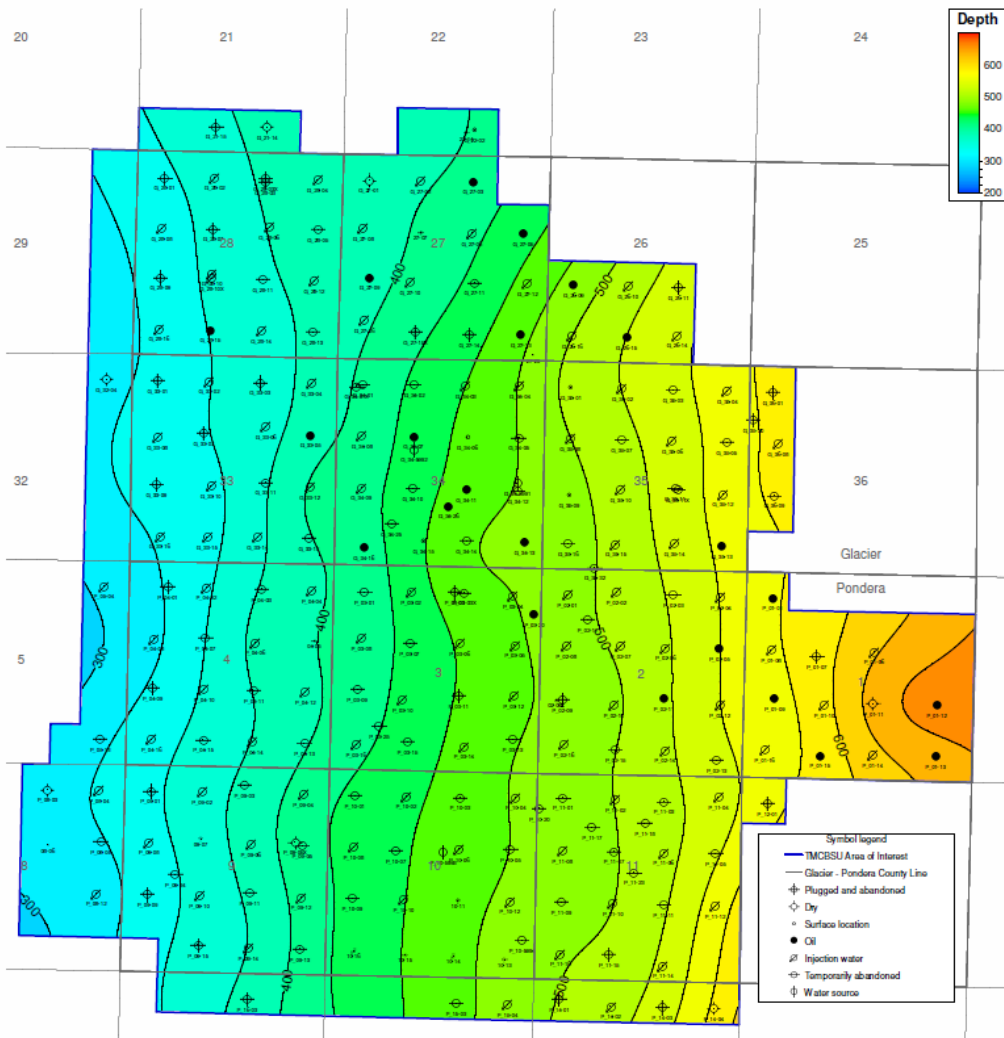




Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Lower Cut Bank Base Structure



Base Lower Cut Bank Structure Map



- Symbol legend
- TMCSJU Area of Interest
 - Glacier - Pondera County Line
 - ⊕ Plugged and abandoned
 - ◇ Dry
 - Surface location
 - Oil
 - ⊕ Injection water
 - ⊕ Temporarily abandoned
 - ⊕ Water source

Structure Map	
Scale	Location
1:10000	Montana
Leaf name	Formation
Area	Oil Wells
Company	Map
Scale/Version	Oil Well
Signature	Company Inc
DWG	25



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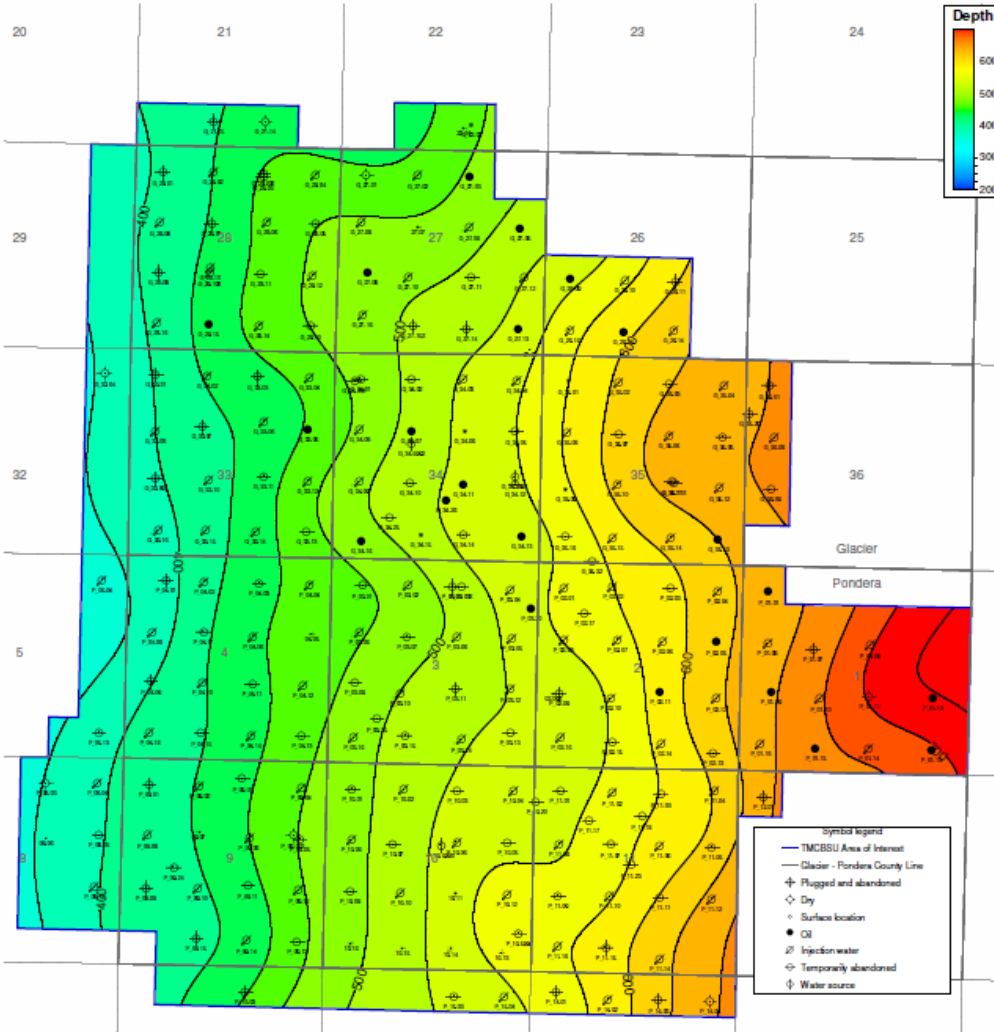
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Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Upper Cut Bank Top Structure



Top Upper Cut Bank Structure Map



- Symbol legend
- TMCBSU Area of Interest
 - Glacier - Pondera County Line
 - ⊕ Plugged and abandoned
 - ◇ Dry
 - Surface location
 - Oil
 - ⊗ Injection water
 - ⊖ Temporarily abandoned
 - ⊕ Water source

Structure Map

Scale	Location
1:10000	Montana
Drawn by	Formulation
Area	Oil field
Company	Date
Schlamberg	2002/2003
Copyright	Contract / no.
© 2002	20



Schlumberger

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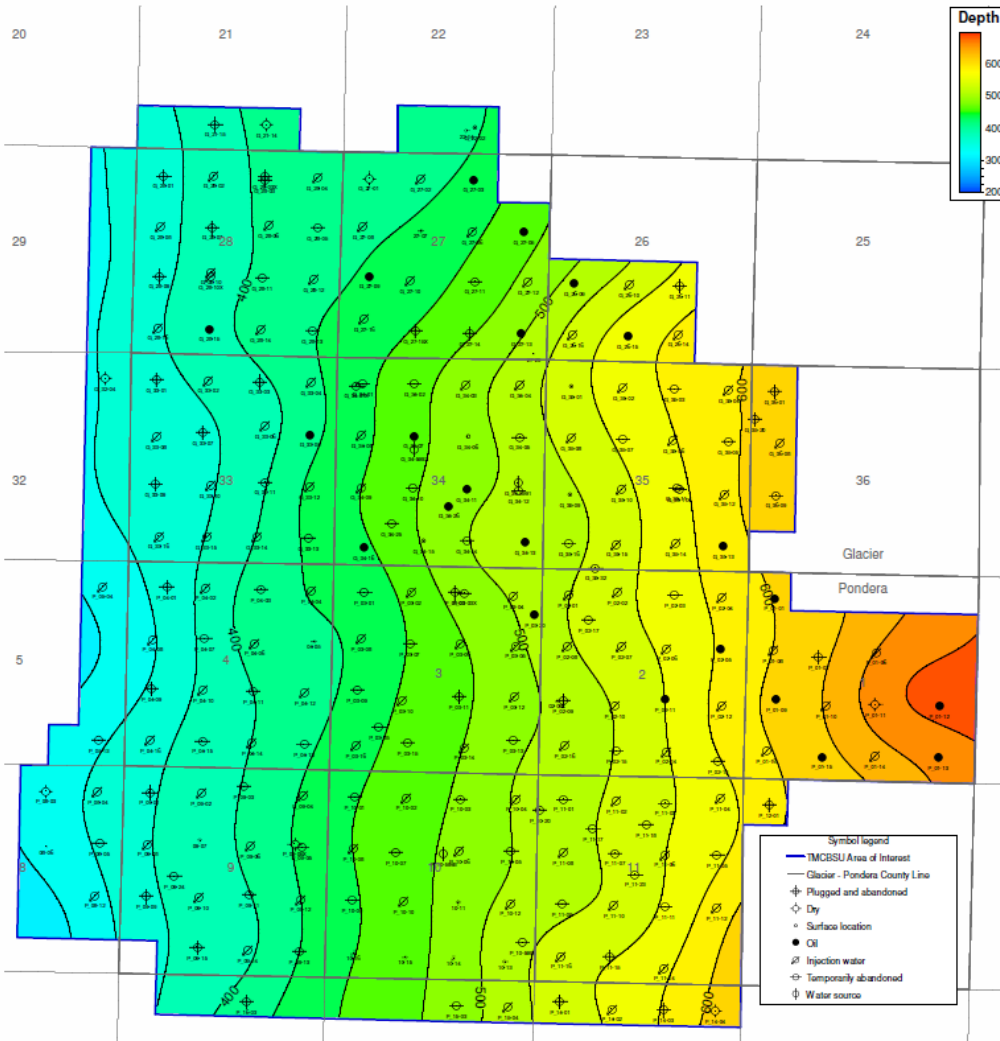
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Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Lower Cut Bank Top Structure



Top Lower Cut Bank Structure Map

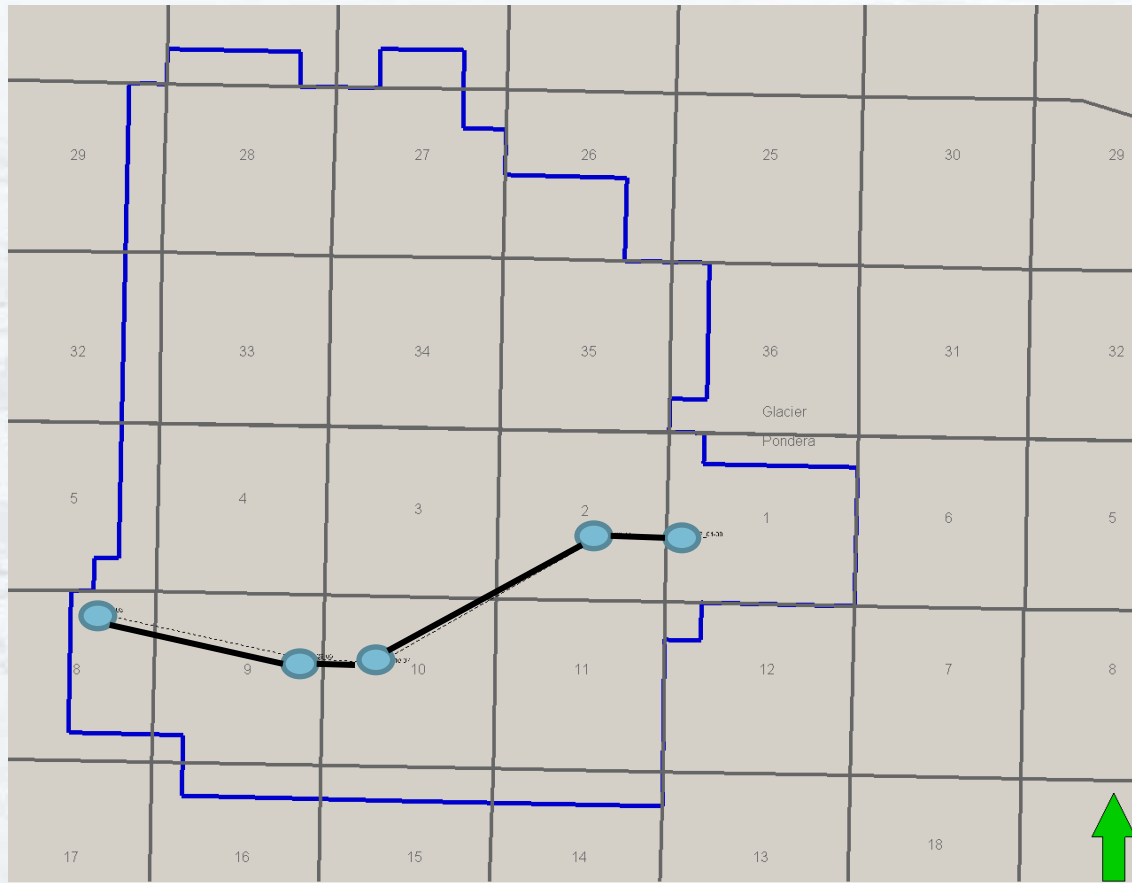


Structure Map

Scale	1:10000	Location	
User name		Formation	
Job		Lock Bank	
Company	Schlumberger	Date	10/24/2010
Segment	Constar inc		
PC	25		



East-West Structural Cross Section



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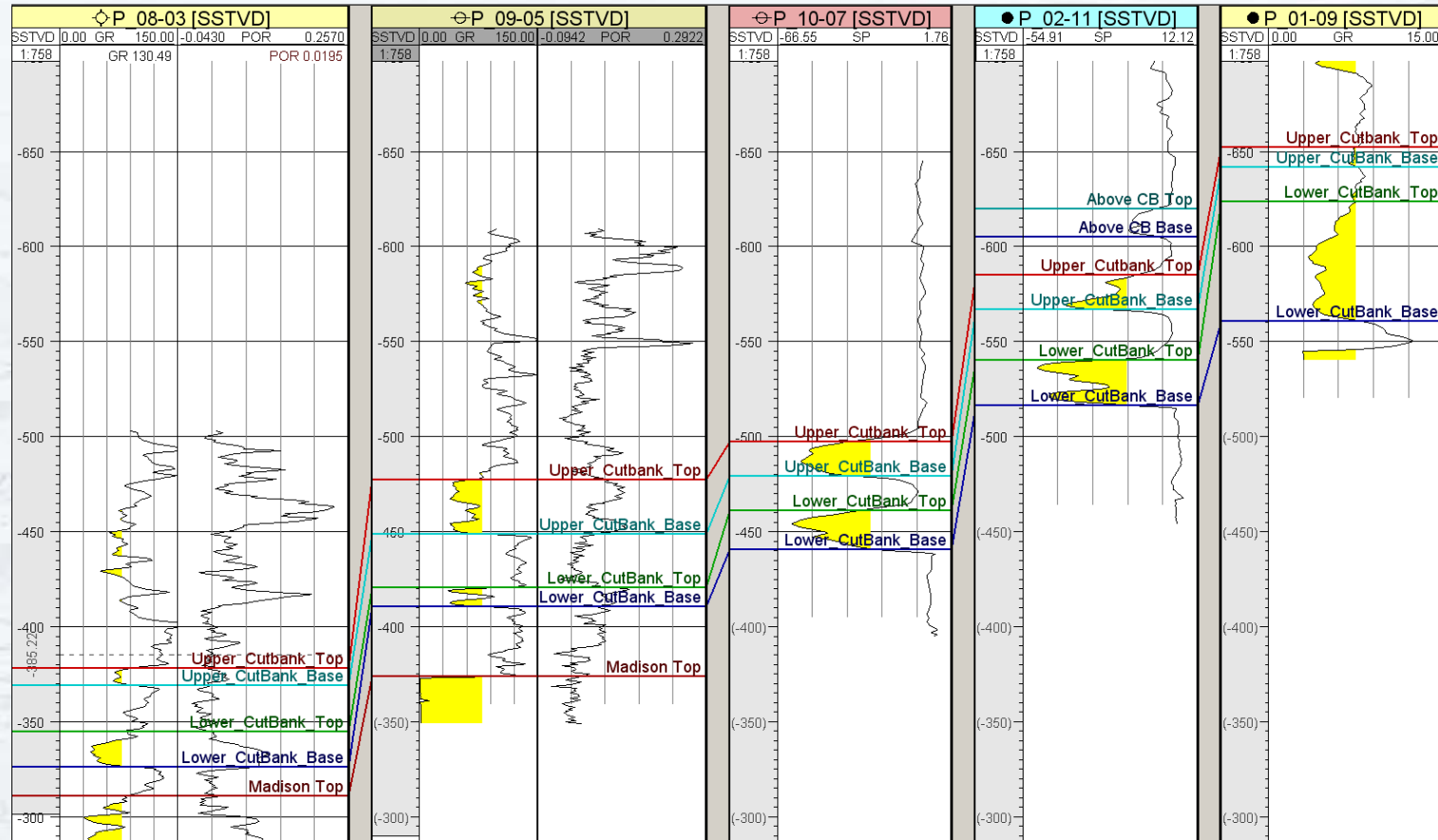
Two Medicine Cut Bank Sand Unit (TMCBSU)



Structural Cross Section West-East

W

E



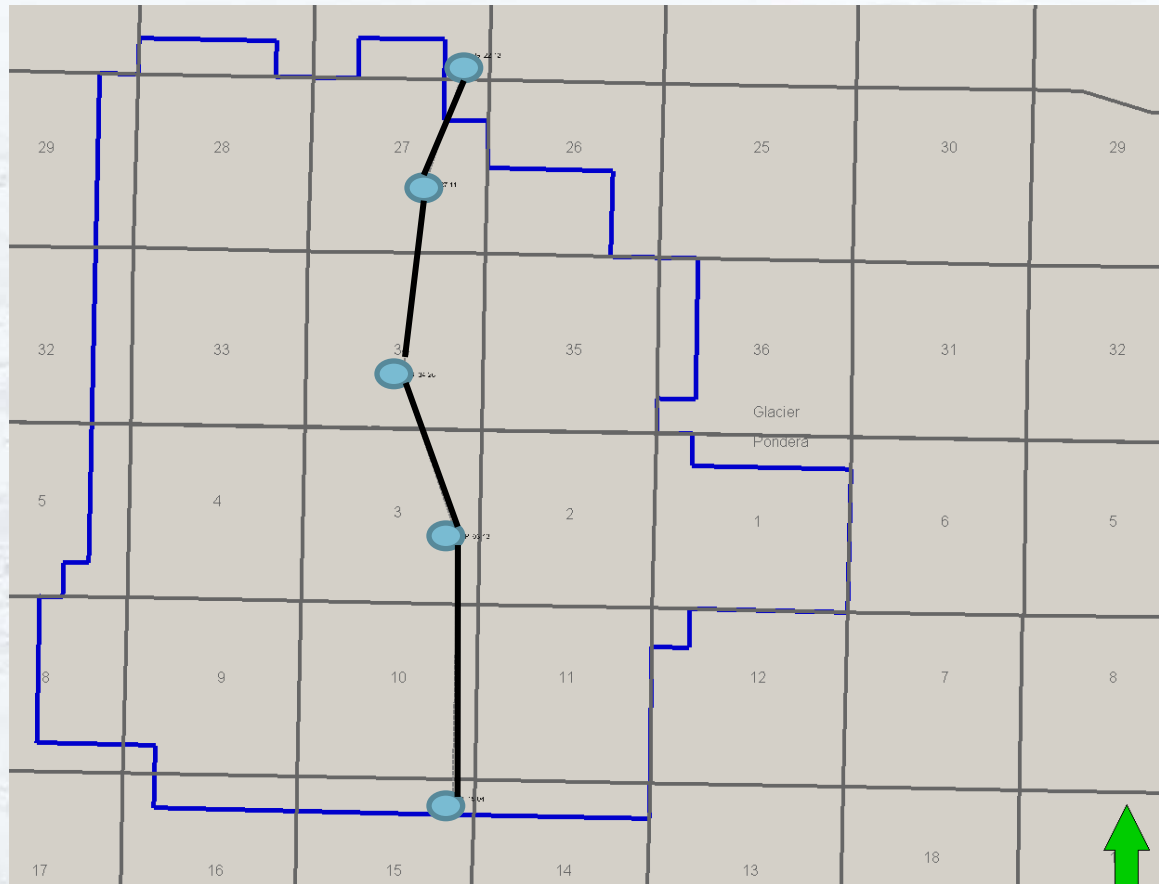
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Two Medicine Cut Bank Sand Unit (TMCBSU)



North-South Stratigraphic Cross Section



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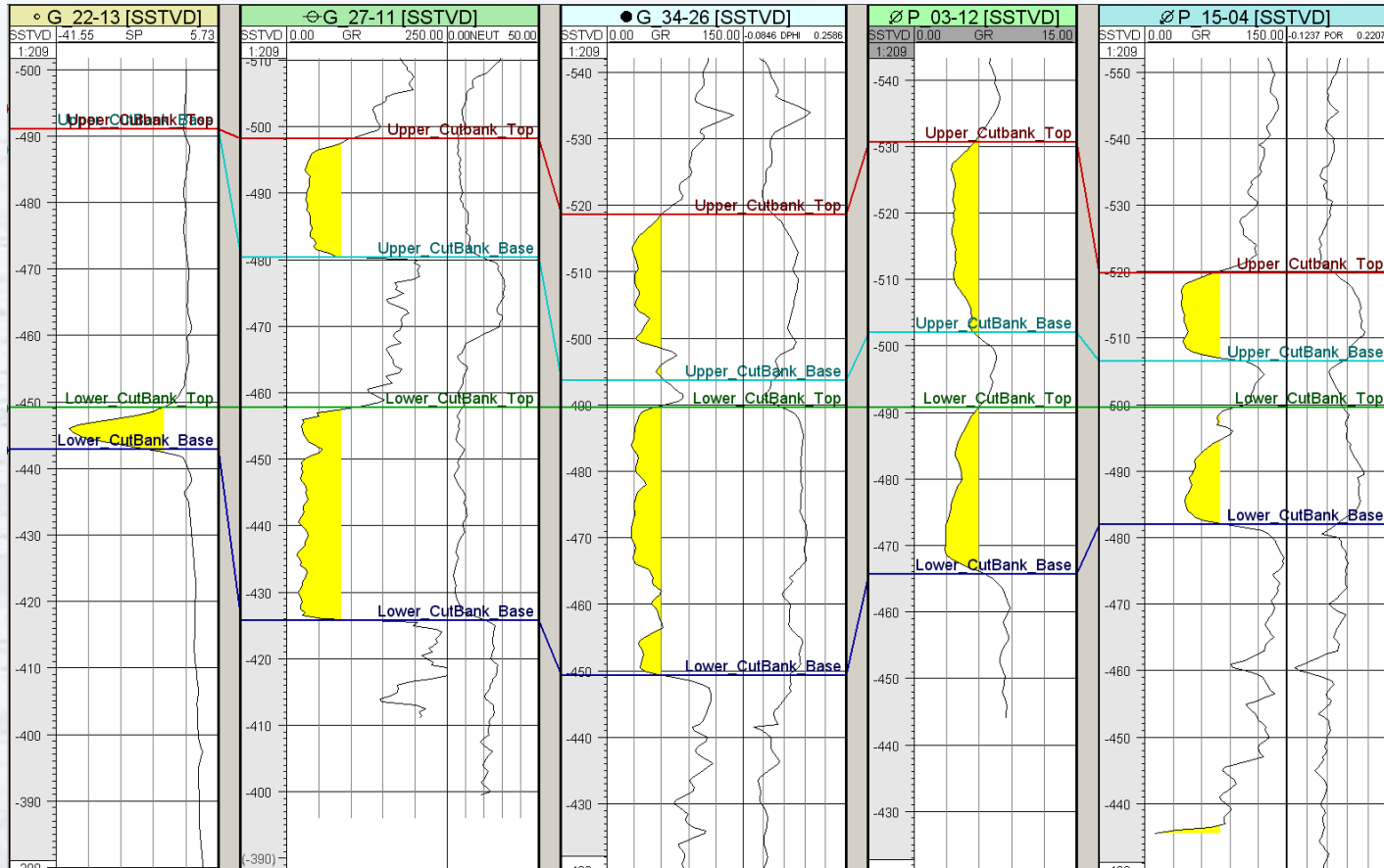
Two Medicine Cut Bank Sand Unit (TMCBSU)



Stratigraphic Cross Section North-South

N

S



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Two Medicine Cut Bank Sand Unit (TMCBSU)



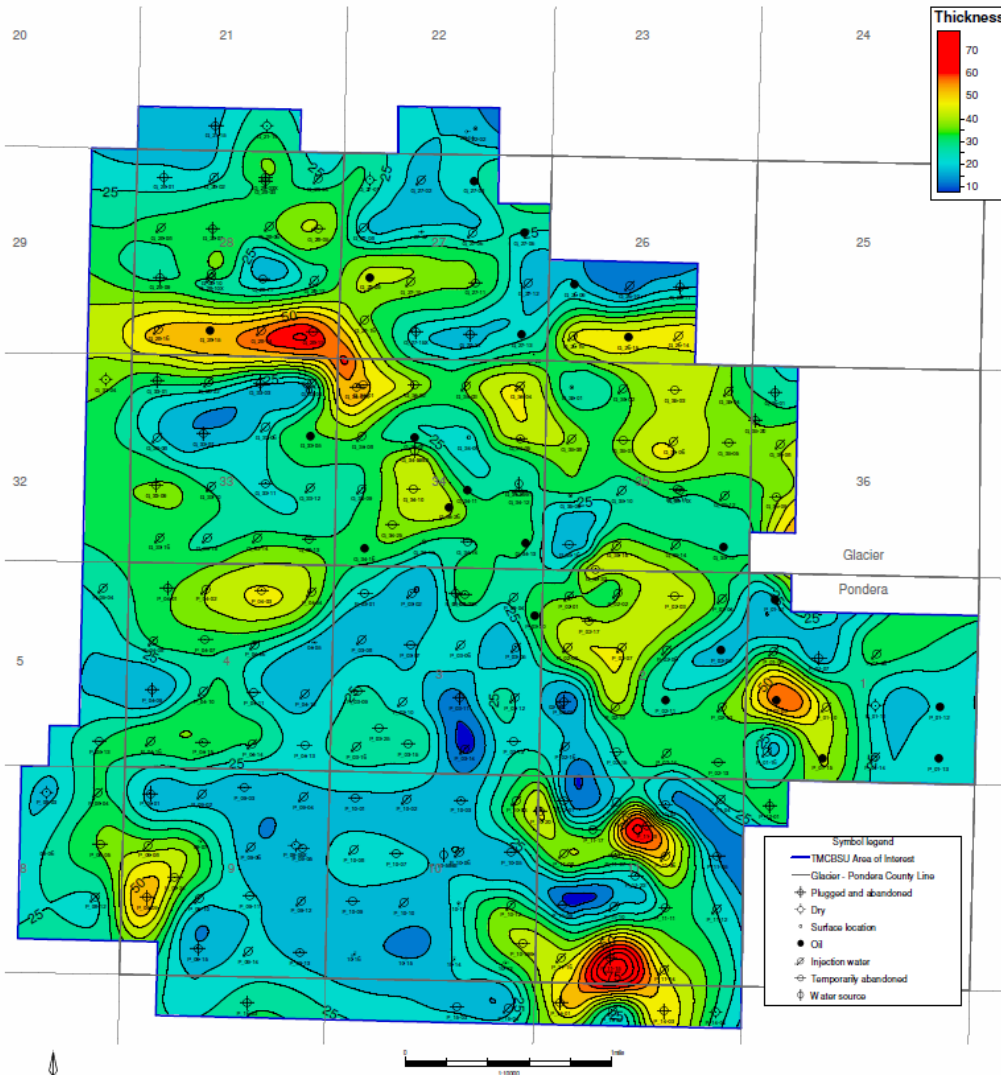


Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana

Lower Cut Bank Gross Sand



Lower Cut Bank Gross Sand Map



Isopach	
Scale	Location
1:10000	Glacier
Leaf Name	Formation
4808	Cut Bank
Scale	Leaf
4808	4808
Segment	Contractor
4808	4808

Lower Cut Bank Sand
Oil bearing Zone
Thickness: 10-78 ft
Irregular fluvial sand geometry
Thin LCB locally in south and north areas

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Cut Bank Depositional Characteristics

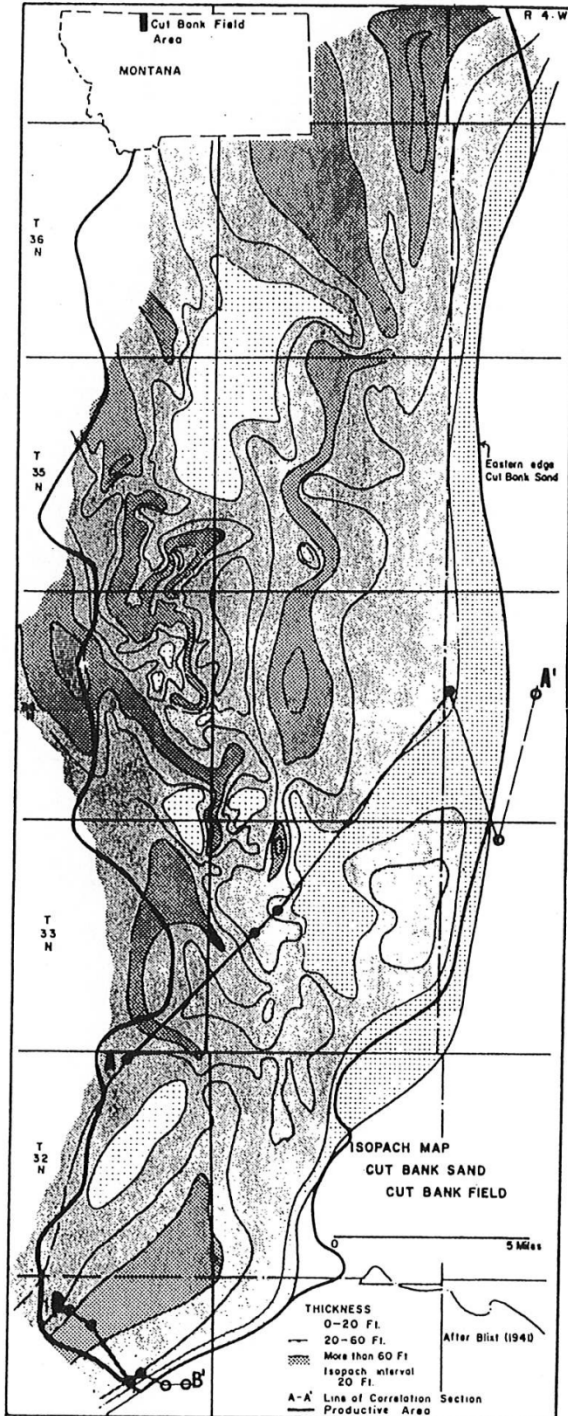
Lower Cretaceous regional drainage to N/NE

Fluvial meandering channel complex, broad paleovalley ~20 ml. width, multistory meander-belt sand bodies

Geometry: Sinuous, channelized sand bodies, ~100ft. to several 100ft. in width, good continuity parallel to channel axis, multistory stacked sands

Thickness: <100ft Field wells, 200ft Outcrop

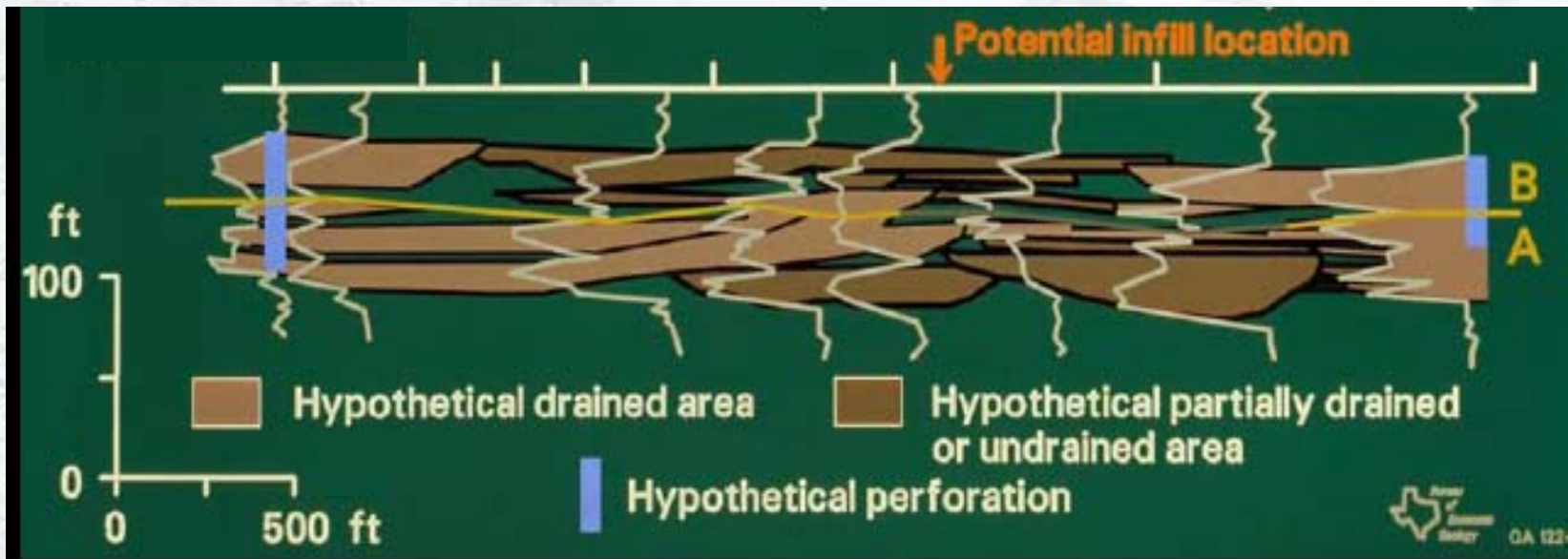
Lithology: medium grained, cross-bedded sandstone, clay mineralogy (premature waterflood failure)



Two Medicine Cut Bank Sand Unit (TMCBSU)

Cut Bank Fluvial Reservoirs - Concept Cross Sectional View

Reservoir: stratigraphic, lateral pinchouts, erosional cross-cutting relationships; directional permeability, heterogeneous flow units



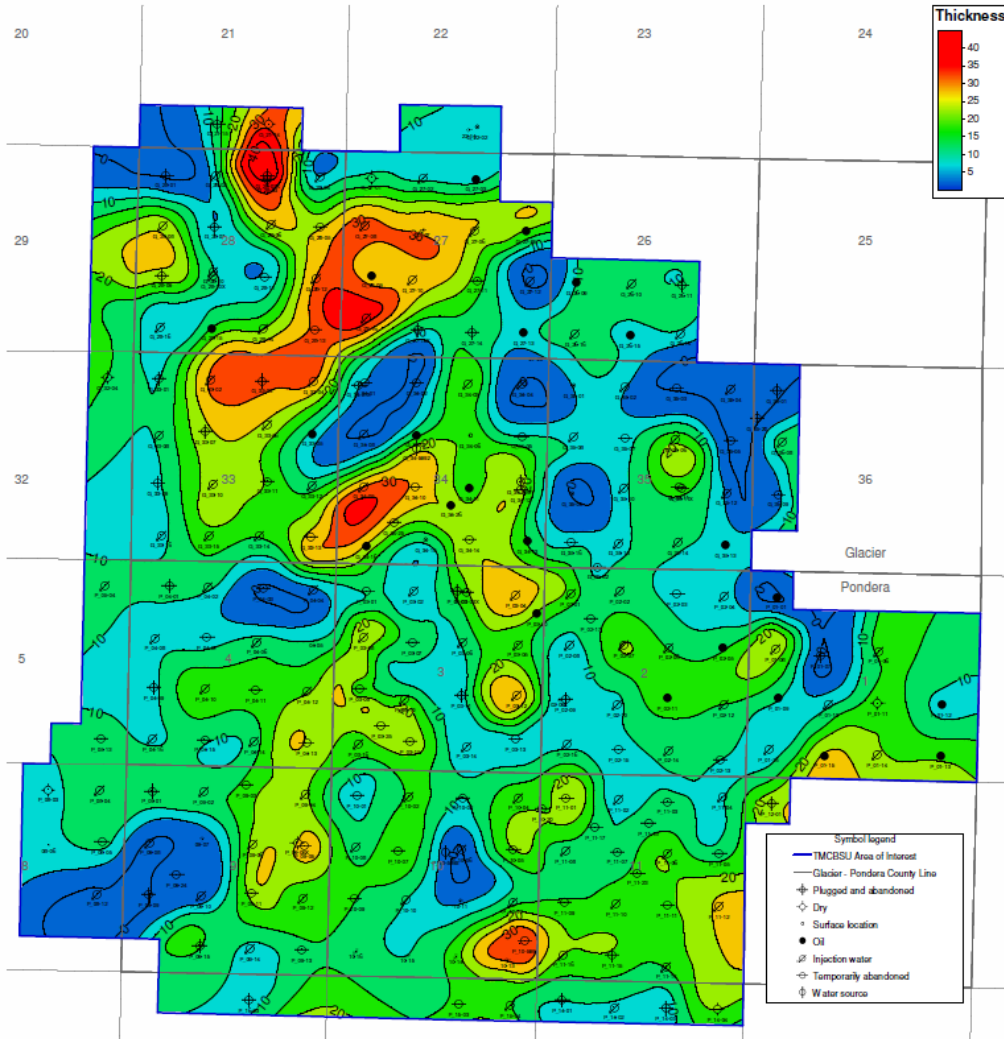
after Jackson et al. (1988)



Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Upper Cut Bank Gross Sand



Upper Cut Bank Gross Sand Map



Upper Cut Bank Sand

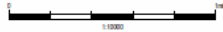
Thickness: 0-44 ft

No UCB locally in North and SW areas

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Isopach	
Scale	Location
1:50000	Montana
Leaf name	Formation
UTM	Oil Field
Company	Map
Schulmberger	Upper Cut Bank
Revised	Contract no.
2008	5



Net Sand Calculation

Lower CB Net Sand =

Lower CB Gross Sand – Shale Break

Lower CB Gross Sand =

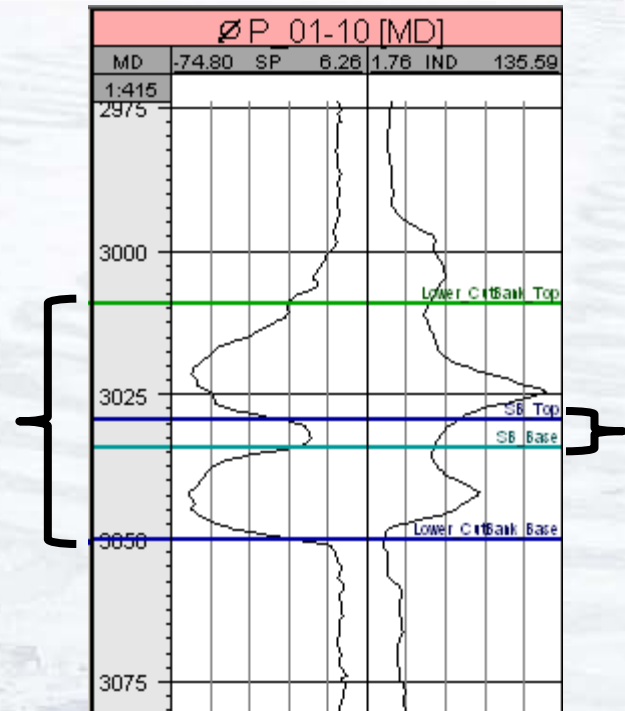
LCB_Top - LCB_Base = 41ft

Shale Break =

SB_Top – SB_Base = 7ft

Lower CB Net Sand =

41ft-7ft =34ft



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Shale Break

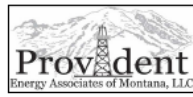


Two Medicine Cut Bank Sand Unit (TMCBSU)



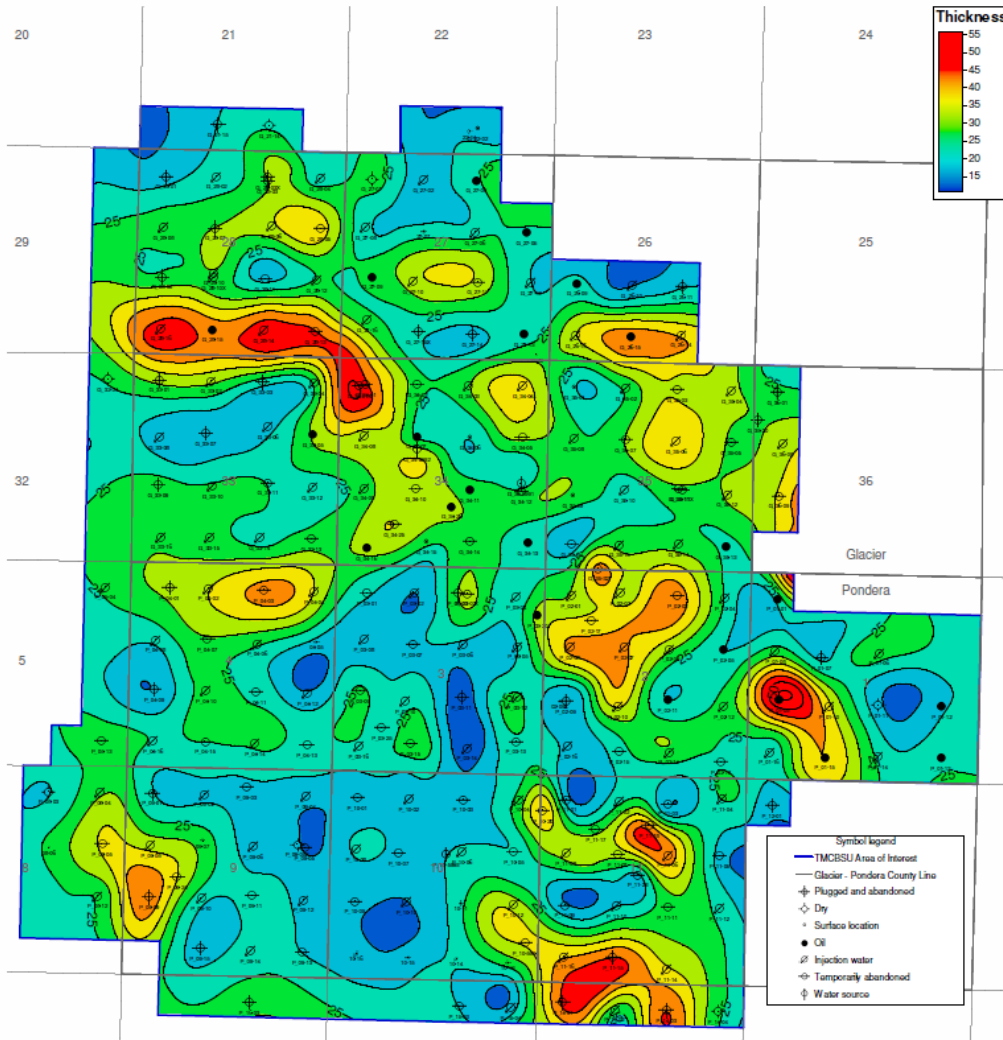


Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Lower Cut Bank Net Sand



Lower Cut Bank Net Sand Map

Net Sand Thickness:
10-55 ft



Isopach	
Scale	Location
1:1,000	Lower Cut Bank
Map name	Formation
UTM	Lower Cut Bank
Company	Date
Schlamberger	02/24/2010
Segment	Contour inc
DCS	S



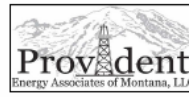
Schlumberger

Schlumberger

Schlumberger Private

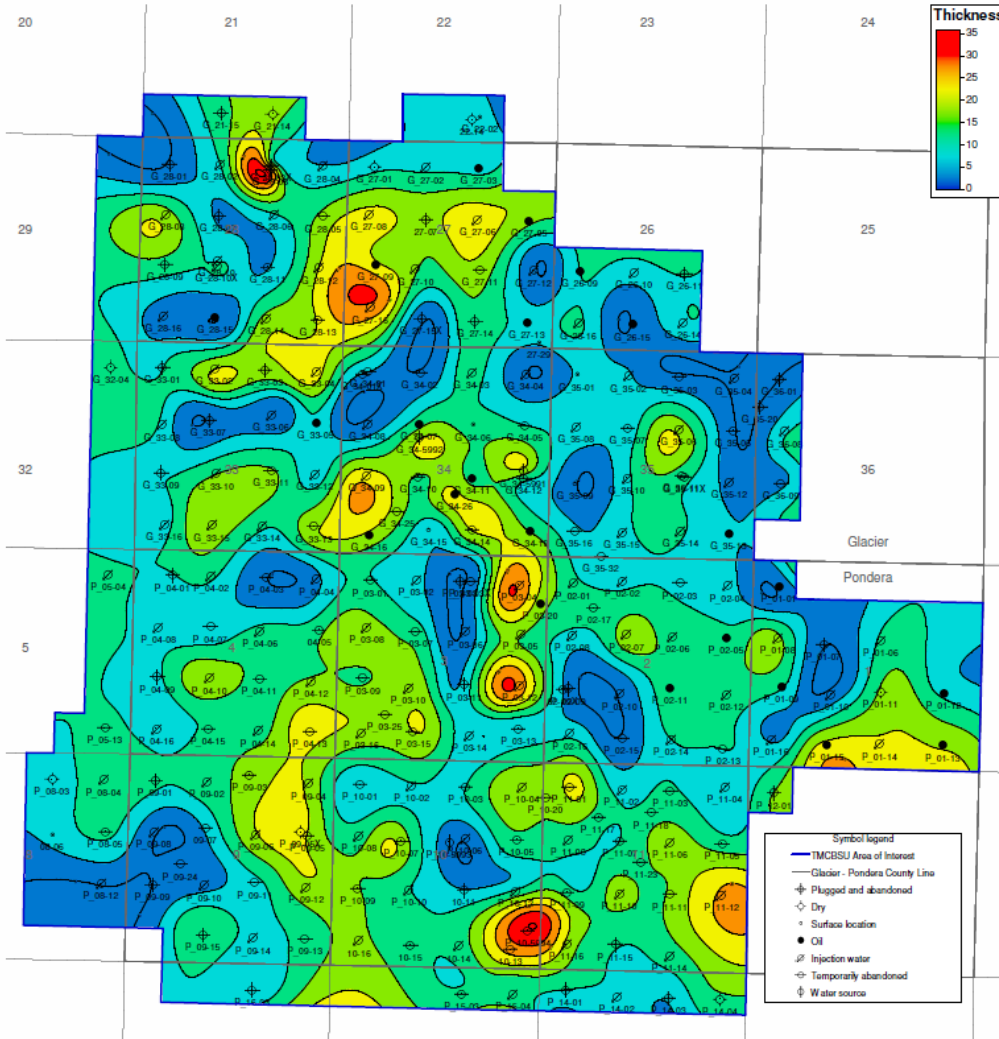


Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Upper Cut Bank Net Sand



Upper Cut Bank Net Sand Map

Net Sand Thickness:
0-38 ft

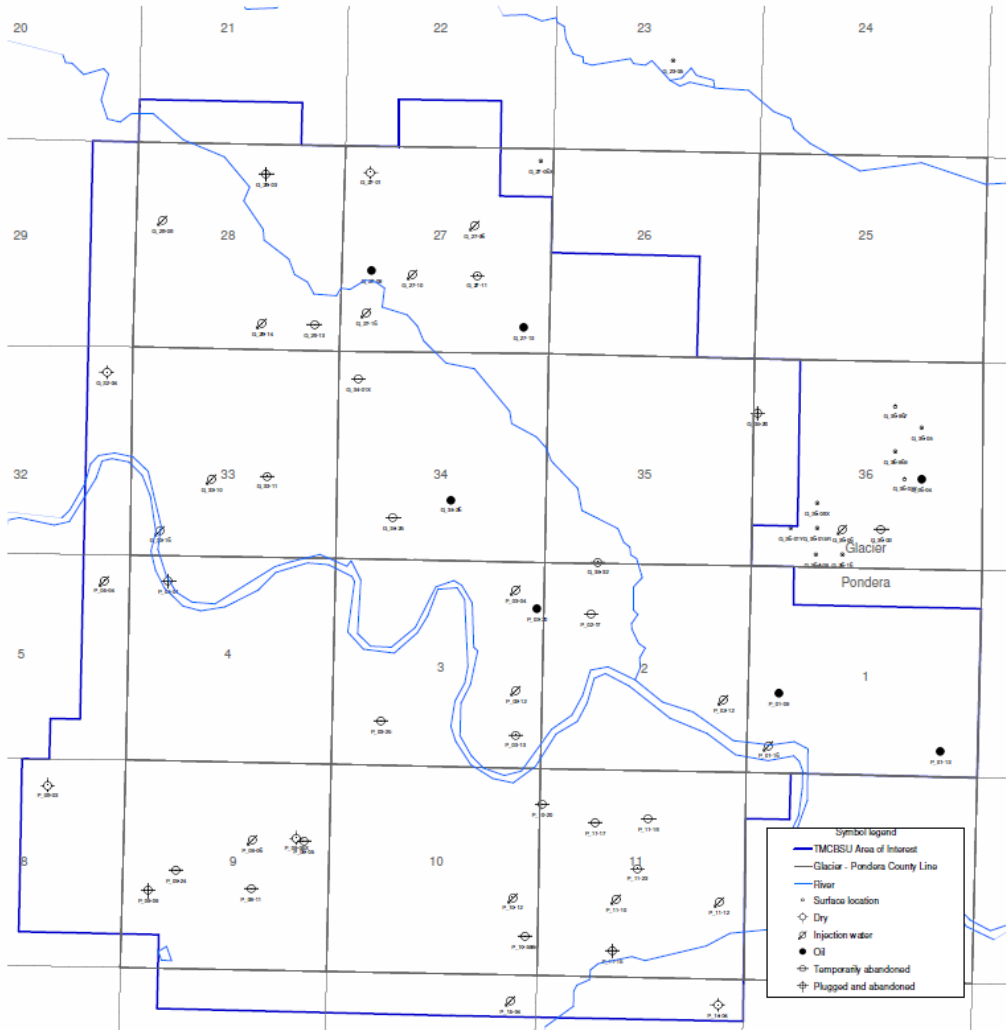


Isospech	
Scale	Location
1:10000	Location
Leaf Name	Formation
WPA	Cut Bank
WPA	WPA
Survey	03/31/2010
Geologist	Contract no.
WPA	16





Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
BASEMAP Wells with Porosity Logs



BASEMAP	
Scale	Segment
1:10000	2025
Author	Location
JJW	2025
Company	Date
Schlumberger	2025-09-24 10:10



Porosity Data

71 Wells with Porosity logs

43 Wells inside TMCBSU

5 Wells outside TMCBSU

4 Porosity Curve Types:
 Por, Neut, DPHI, NPHI

1972 Core Analysis Results:

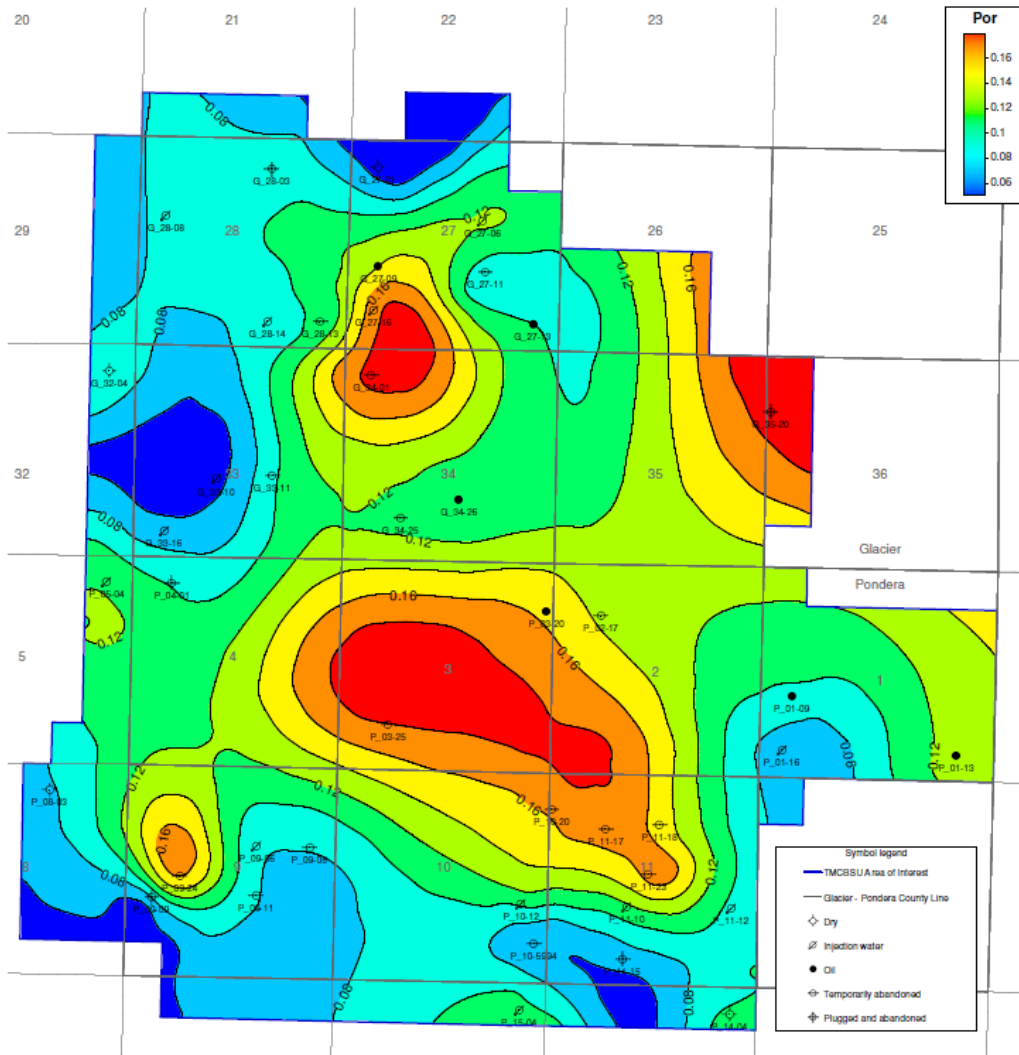
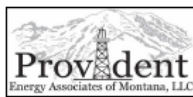
Porosity (Φ): 12.7% (avg)
 range 1 to 18%

Permeability (k): 44.6 mD (avg)
 range 1mD to 897 mD





Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
 Lower Cut Bank Porosity



Symbol legend

- TMCBSU Area of Interest
- Glacier - Pondera County Line
- ◇ Dry
- ⊕ Injection water
- Oil
- ⊕ Temporarily abandoned
- ⊕ Plugged and abandoned

Porosity Map	
Scale	Location
1:3000	Two Medicine
Unit name	Formation
⊕	Cut Bank
Company	Date
Schlumberger	09/25/2010
Segment	Contour Int
LC5	0.02

Porosity Map Based on 43 Wells



Lower Cut Bank Porosity Map

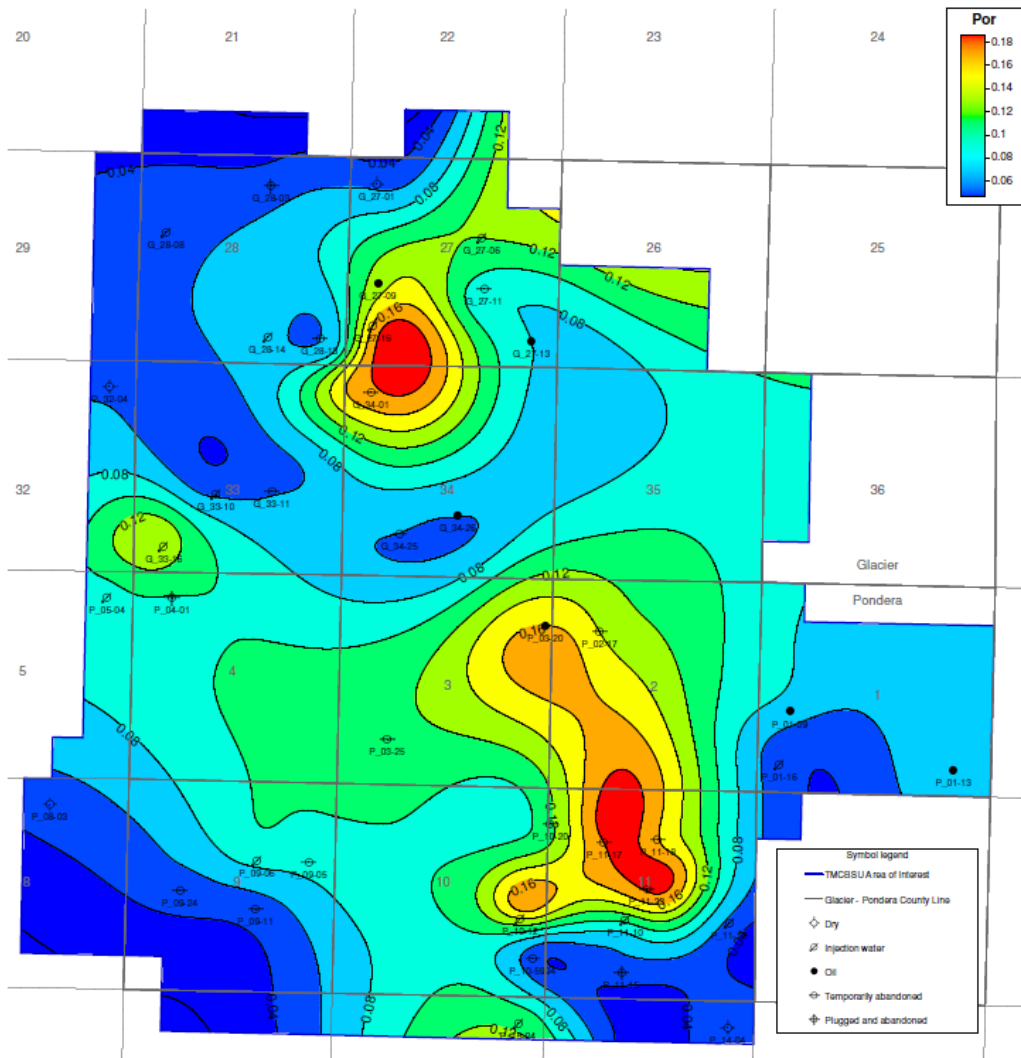
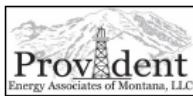
Porosity Map based on
 43 Wells in TMCBSU,
 5 Wells outside TMCBSU
 Av Porosity range 5 – 19 %
 Average 11%
 G 27-01 ϕ 5% Dry
 Cut off 6% Contour

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Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
 Upper Cut Bank Porosity



Porosity Map Based on 41 Wells

Porosity Map	
Scale	1:10000
Unit name	Formation
Unit	Cut Bank
Company	Arkanova
Segment	Upper Cut Bank
Version	0.01



Upper Cut Bank Porosity Map

Porosity Log Control

41 Wells in TMCBSU

5 Wells outside TMCBSU

Av Porosity range 5-18%

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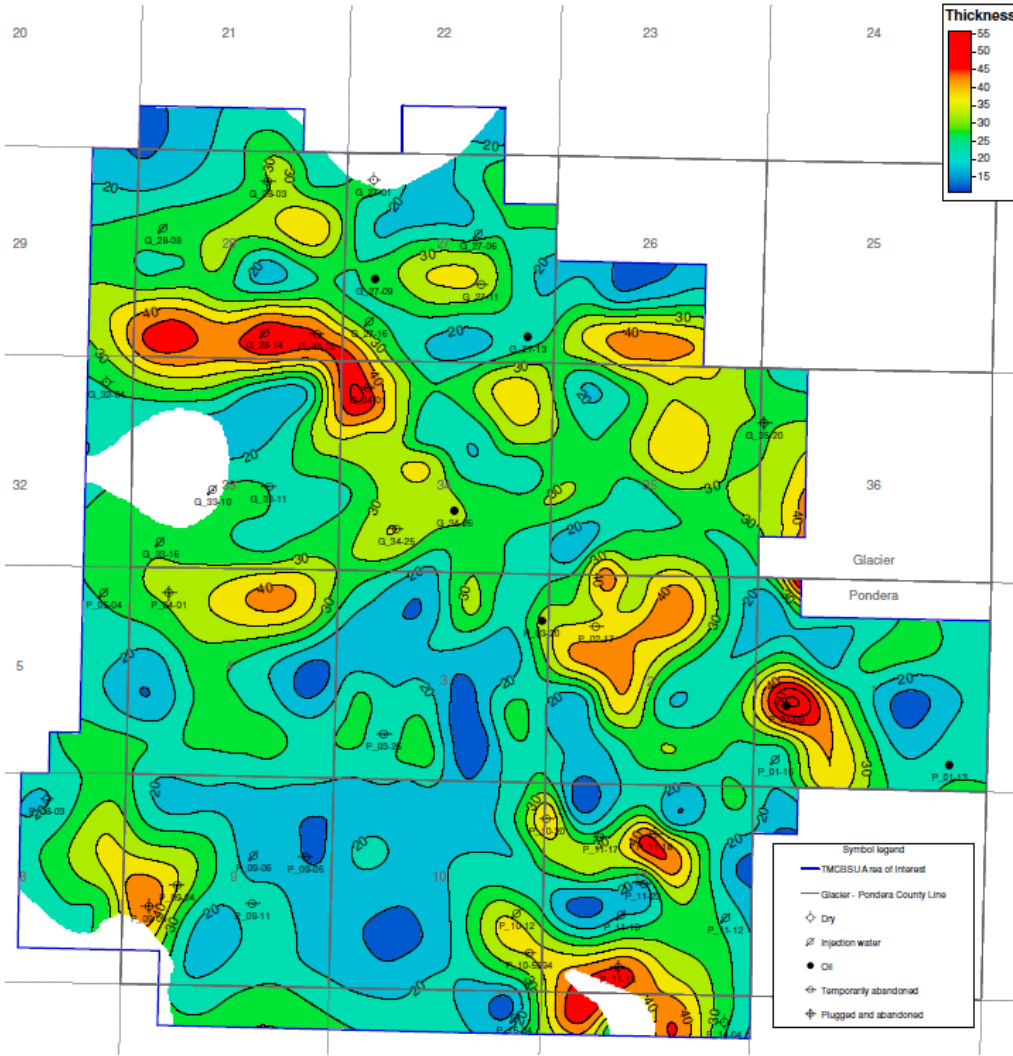
Two Medicine Cut Bank Sand Unit

Glacier and Pondera Counties, Montana

Lower Cut Bank Net Pay



Lower Cut Bank Net Pay



Pay Criteria:

Net Sand Thickness

Porosity cut off 0.6

No OWC - resistivity logs

Net Pay Thickness

Range 12 to 55 ft

>25 ft over >50 % Field

- Symbol legend
- TMCBSU Area of Interest
 - Glacier - Pondera County Line
 - ◇ Dry
 - ⊕ Injection water
 - Oil
 - ⊖ Temporarily abandoned
 - ⊕ Plugged and abandoned

Isopach	
Scale	Location
1:10000	Glacier
Unit name	Formation
Two Medicine	Cut Bank
Company	Case
Schlumberger	20080000
Segment	Lower
DCS	6

Porosity Cutoff 0.06
No OWC



Observations

Structure Dip ~350 ft E-W, ~90ft/mile

Average LCB Gross Sand thickness 29ft

Average Porosity 0.11

Average LCB Net Pay Thickness 26 ft, range 12 to 55ft

No OWC confirmed in LCB

Reservoir Heterogeneity observed in sand distribution and reservoir quality (porosity)

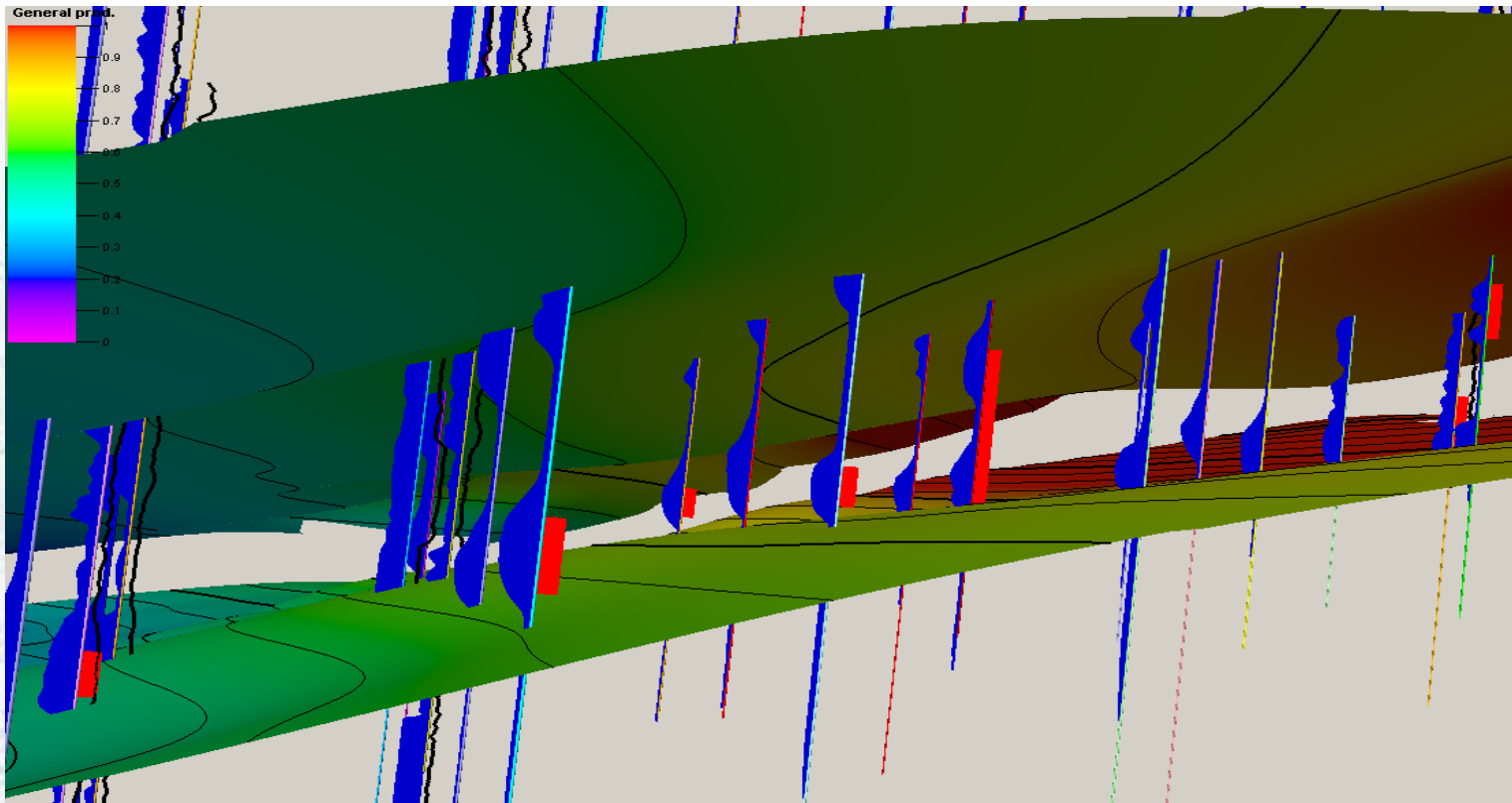
South part of the field has more areas with low reservoir quality (porosity and net sand).



Two Medicine Cut Bank Sand Unit (TMCBSU)



Geological Model in Petrel



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Petrel Project - Wells, Logs, Surfaces, Geological Markers, Production Cums, Perforations, Cultural data



Two Medicine Cut Bank Sand Unit (TMCBSU)



Initial Geological Review:

Geological Control on LCB Production

LCB Net Pay relative to TMCBSU Production

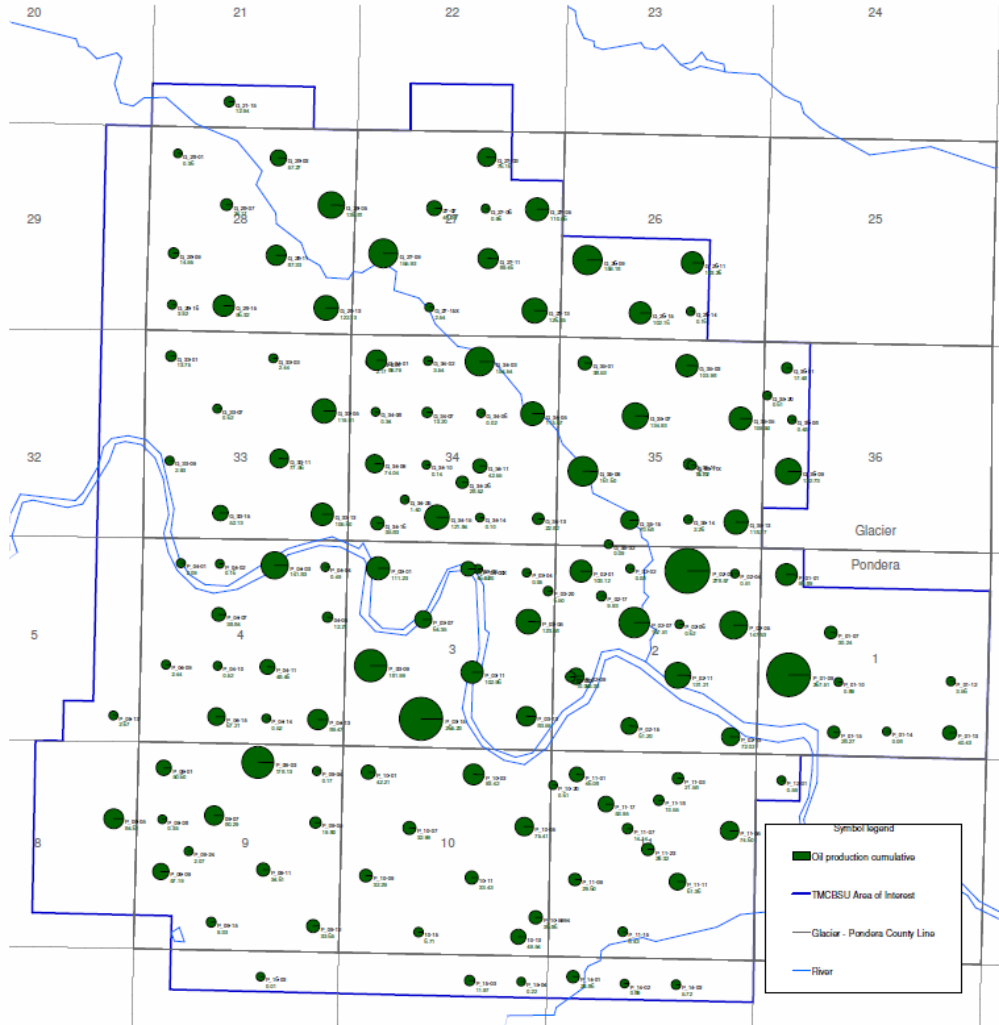
Top 10 Producers

Focus Area - Section 34





Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
 Cumulative Oil Production Bubble Map

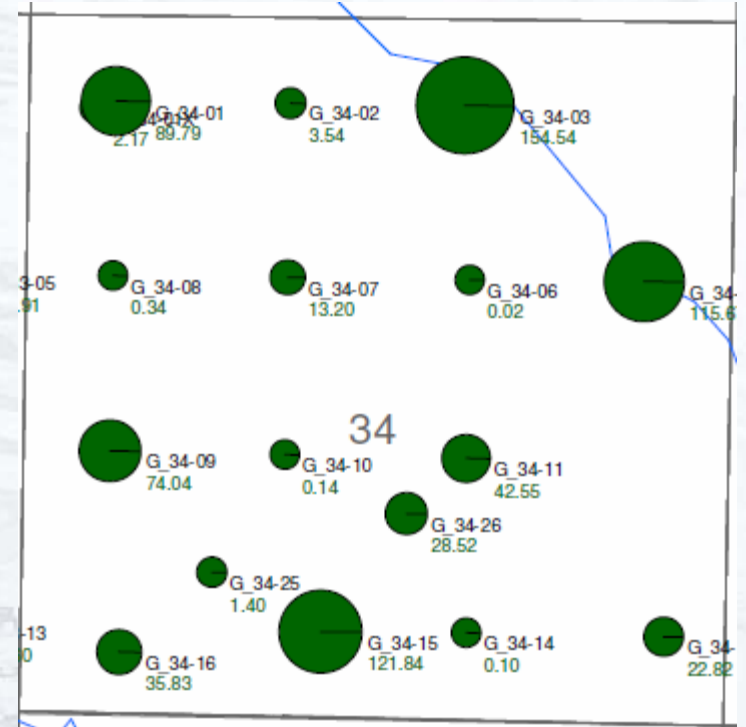


BASEMAP	
Scale	Location
1:10000	Section
Author	Date
File	09/29/2010
Company	Formation
Schlumberger	Cut Bank
Segment	UTM
NWSE	MEW



Schlumberger

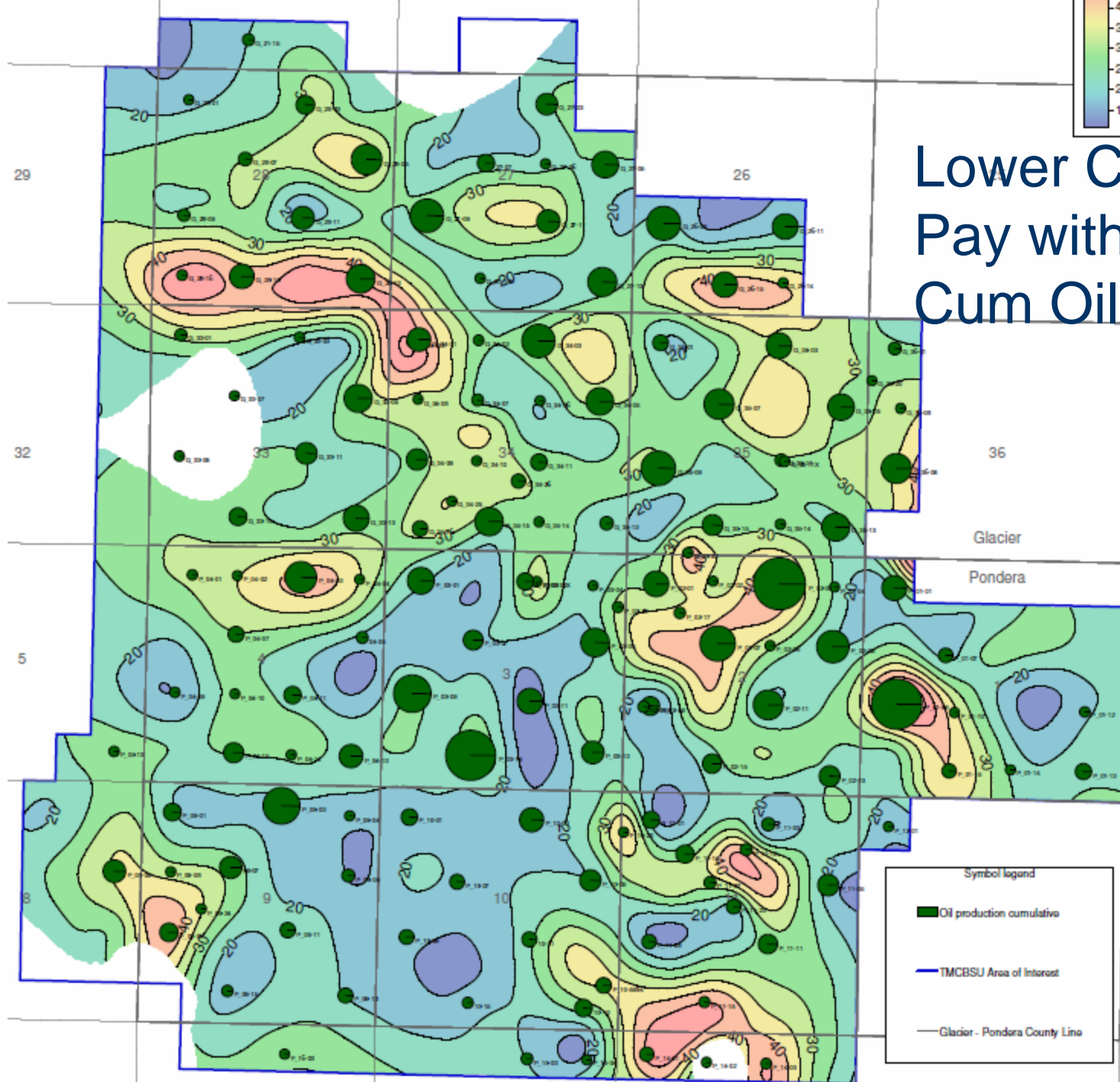
Oil Cum Bubble Map Lower Cut Bank



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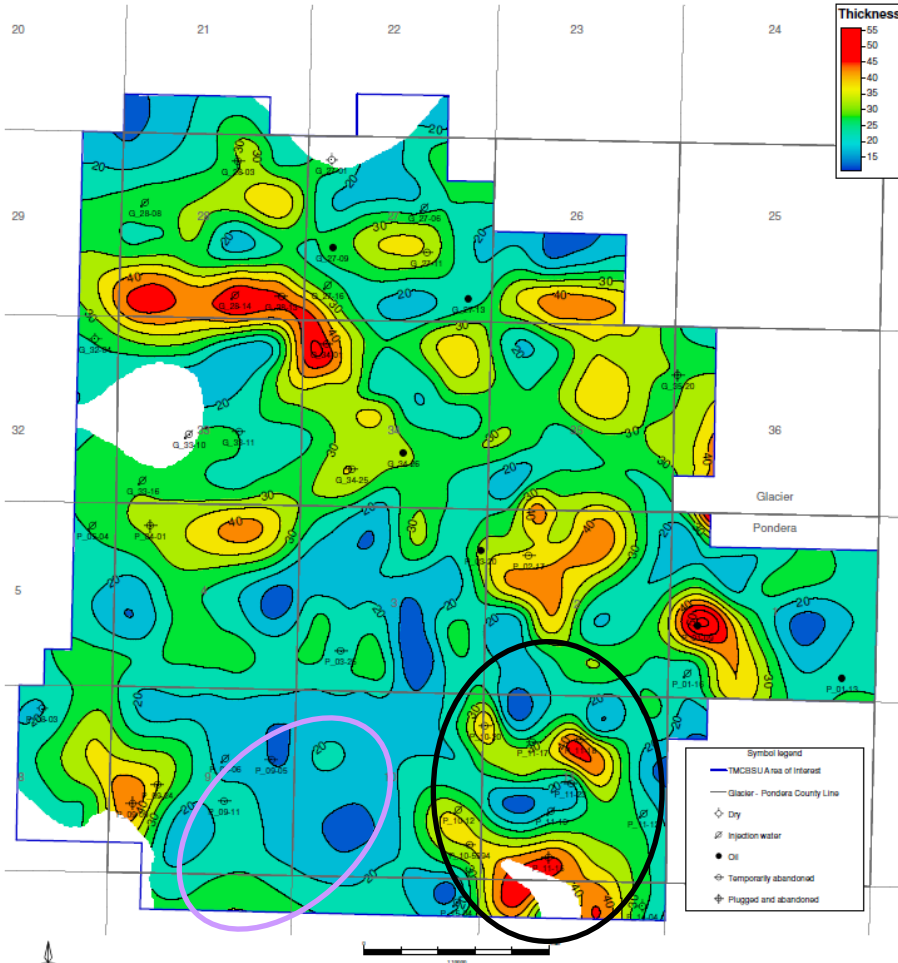
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Lower Cut Bank Net Pay with Cum Oil Production





Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
Lower Cut Bank Net Pay



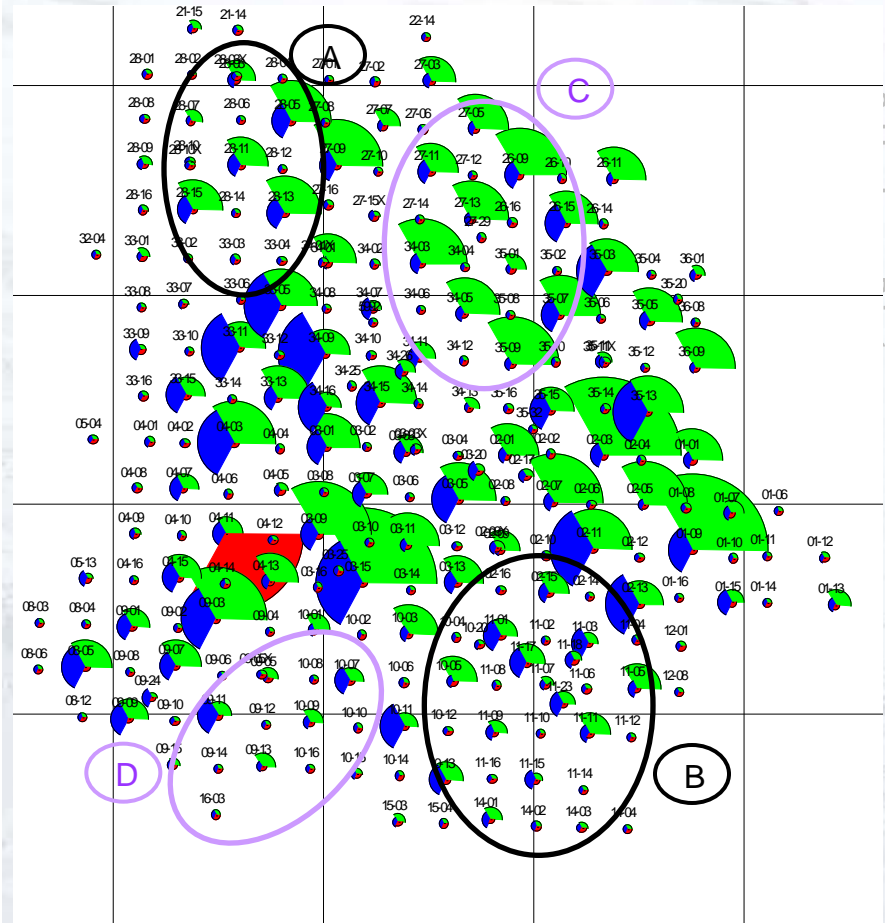
- Symbol legend
- TMCBSU Area of Interest
 - Glacier - Pondera County Line
 - ◇ Dry
 - ⊕ Injection water
 - Oil
 - ⊕ Temporarily abandoned
 - ⊕ Plugged and abandoned

Isopach	
Scale	Horizontal
Unit	Feet
Map name	Lower Cut Bank
Client	Provident
Scale	1:50,000
Created	10/20/11
Revised	10/20/11

Porosity Cutoff 0.06
 No OWC

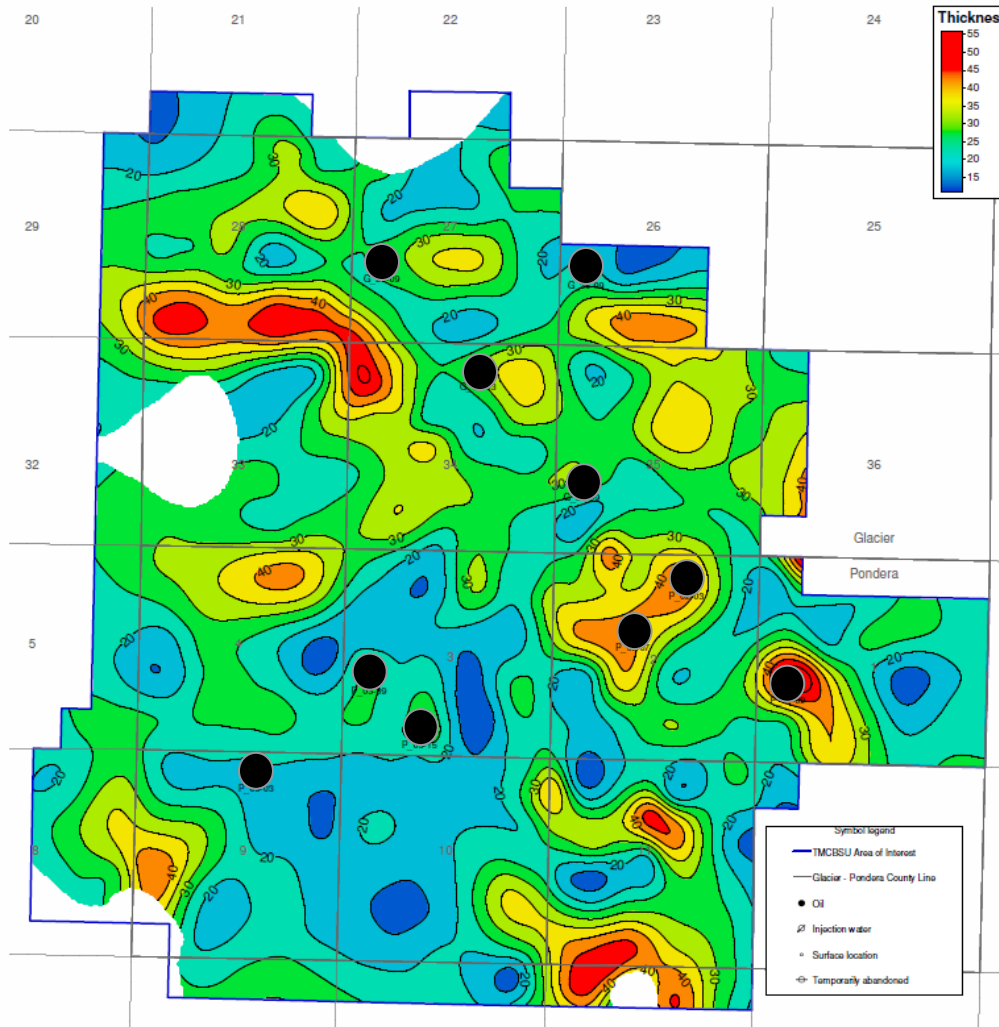


Lower Cut Bank Quality affecting Production



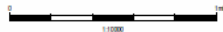


Two Medicine Cut Bank Sand Unit
Glacier and Pondera Counties, Montana
 Net Pay with Top 10 Producers



- Symbol legend
- TMCESU Area of Interest
 - Glacier - Pondera County Line
 - Oil
 - ⊕ Injection water
 - ⊙ Surface location
 - ⊕ Temporarily abandoned

Isopach	
Scale	Segment
Latitude	Contour
Author	Location
Client	Revision
Company	Date
Scale	1/2" = 100' (1:200)



Top 10 Producers Lower Cut Bank

Cum oil production
>150 Mbbl

Range 155 – 279 Mbbl

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TMCBSU Top 10 Producers

– Lower Cut Bank

TMCBSU TOP PRODUCERS

Well Name	Cum Oil Production Mbbl	Perf Interval ft.	Years on Production	Top LCB TVDSS ft.	LCB Gross Th ft.	LCB Net Pay Th ft.	LCB Av. Porosity
P 02-03	279	27	13	566	42	42	0.12
P 01-09	268	38	27	617	58	54	0.07
P 03-15	265	24	21	461	28	28	0.17
P 03-09	182	14	13	432	26	26	0.19
P 09-03	178	11	24	393	17	17	0.13
P 02-07	168	20	10	545	44	41	0.13
G 35-09	162	30	13	517	29	29	0.11
G 26-09	159	18	20	504	21	21	0.07
G 27-09	156	21	17	432	40	26	0.10
G 34-03	155	2	15	492	36	30	0.13

AVERAGE GROSS THICKNESS FT.	29
AVERAGE PAY THICKNESS FT.	26
AVERAGE POROSITY	0.11
TOP LCB STRUCTURE	670

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Two Medicine Cut Bank Sand Unit (TMCBSU)



Observations - Top Producers >150Mbbbl

Structurally higher locations

Gross and net pay thickness above field average
LCB Gross (29ft) and Net Pay (26ft) thickness,

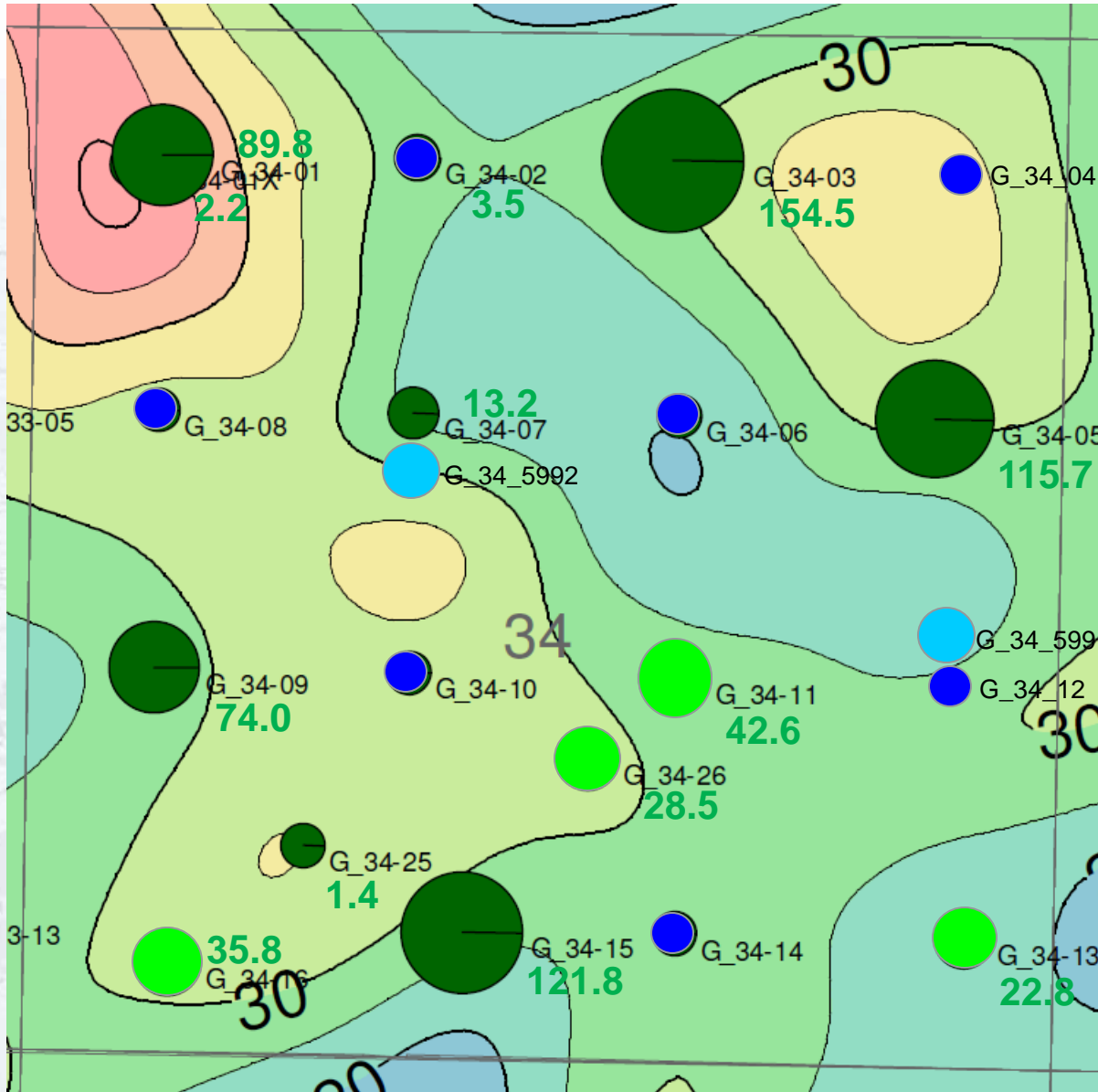
Sand porosity above 0.11

Years on Production >10

Perforation interval variable 2 – 27ft

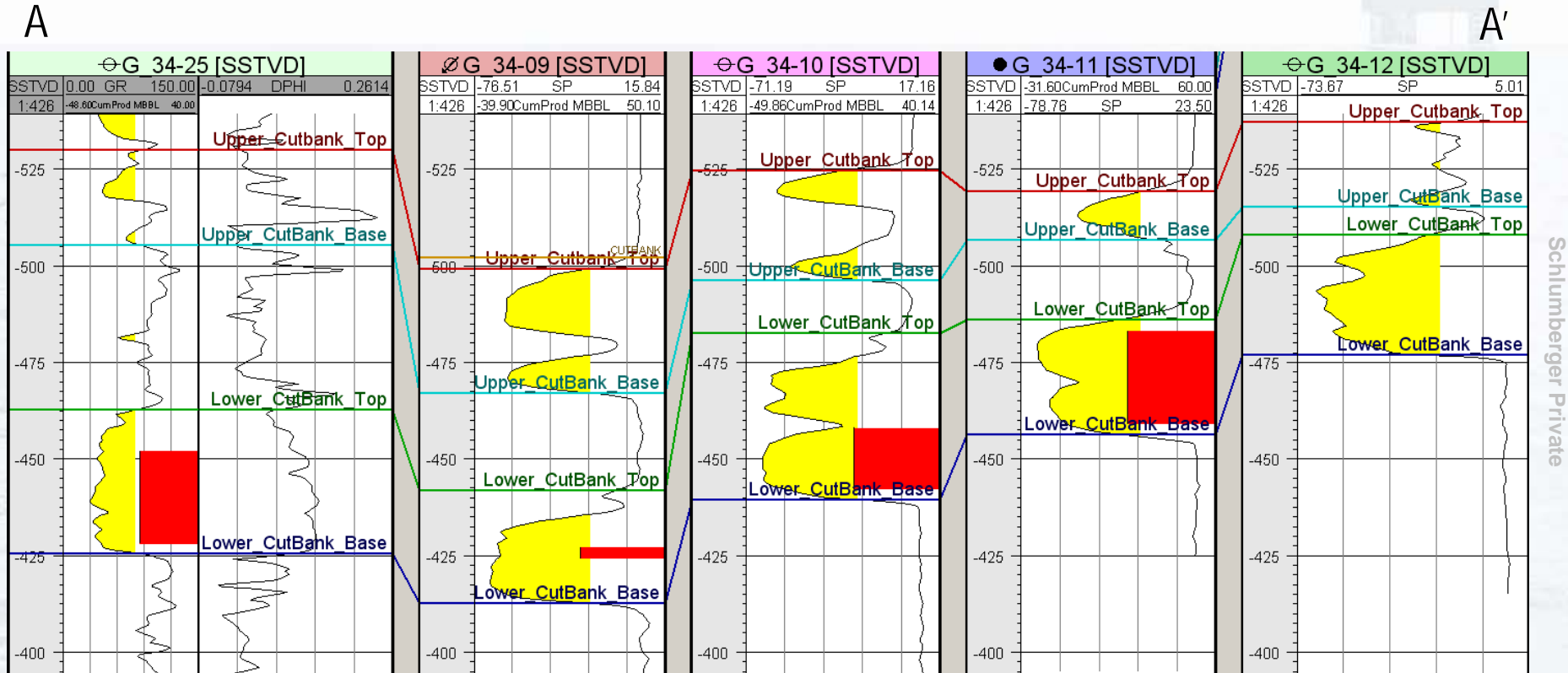


TMCBSU Glacier Section 34 Production – Lower Cut Bank

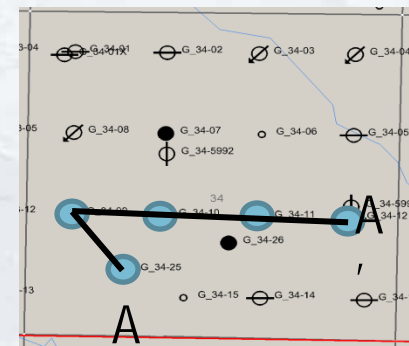


Representative
Section from Field
21 wells
12 Producers
4 Active
Producers

TMCBSU Glacier Section 34 E-W Cross section

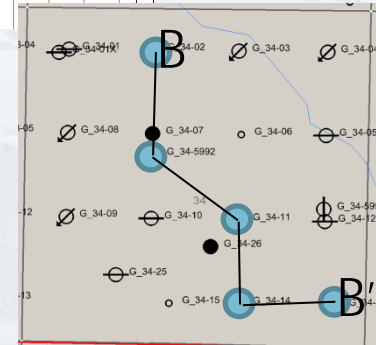
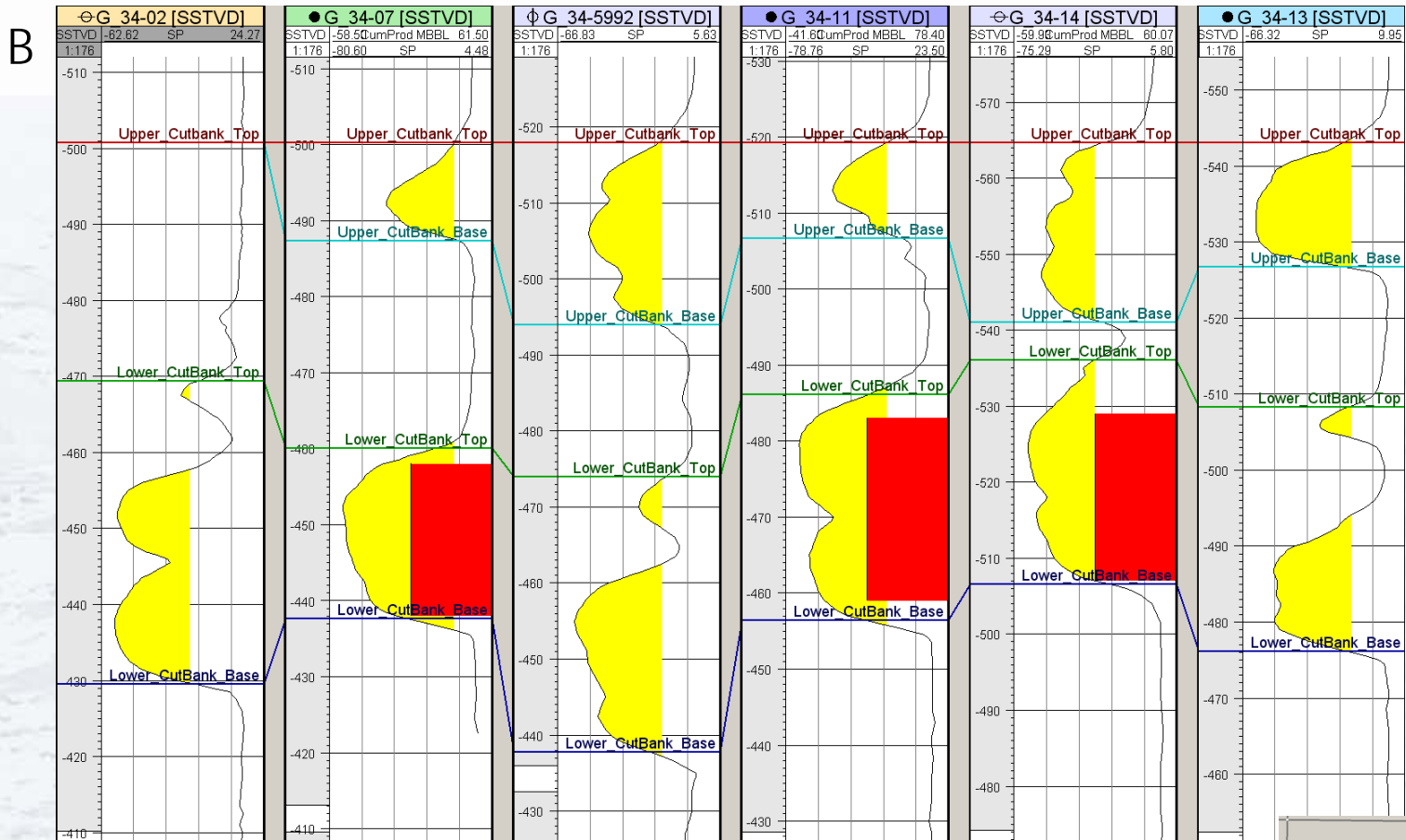


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Two Medicine Cut Bank Sand Unit (TMCBSU)

TMCBSU Glacier Section 34 N-S Cross section



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TMCBSU Glacier Section 34



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Well Name	Status	Cum Oil Production Mbbl	Perf Interval ft.	Years on Production	Top LCB TVDSS ft.	LCB Gross Th ft.	LCB Net Pay Th ft.	LCB Av. Porosity
34-03	OIL_SI	154.5	2	16	492	35	28	0.14
34-15	OIL_SI	121.8	23	19	476	30	26	0.12
34-05	OIL_SI	115.7		10	506	41	31	0.11
34-01	OIL_P&A	89.8		10	459	47	45	0.18
34-09	OIL_SI	74.0	3	15	441	29	26	0.12
34-11	OIL_ACT	42.6	24	29	485	29	26	0.11
34-16	OIL_ACT	35.8	16	20	455	32	19	0.12
34-26	OIL_ACT	28.5	22	18	489	41	31	0.11
34-13	OIL_ACT	22.8		8	507	31	21	0.12
34-07	OIL_SI	13.2	20	13	459	22	22	0.15
34-02	INJ	3.5		0.3	469	40	27	0.18
34-01X	OIL_SI	2.2		4	459	54	51	0.18
34-25	OIL_SI	1.4	24	2	462	37	35	0.12
34-08	INJ	0.3		0.1	437	34	32	0.15
34-10	INJ	0.1	16	1	482	43	34	0.12
34-14	INJ	0.1	22	0.5	536	30	28	0.12
34-06	INJ	0.0	16	0.1	482	21	19	0.12
34-04	INJ	0.0		0	518	45	37	0.11
34-12	INJ	0.0		0	507	30	26	0.11
5991	Water Source				497	19	16	
5992	Water Source				474	36	31.2	

AVERAGE GROSS THICKNESS FT.	29
AVERAGE PAY THICKNESS FT.	26
AVERAGE POROSITY	0.11



Observations – Glacier Section 34

CB Sand profiles change in thickness, shale breaks, heterogenous fluvial reservoir

Productive wells (13 - 151 Mbbl) in similar structural position in field (441 – 507 ft TVD)

Many Producers associated with above average LCB Gross (29ft) and Net Pay (26ft) thickness, and Porosity >0.11

Years on Production - Broad range 8 to 29 years

Perforation interval - Variable 8 to 29 ft.

Waterflood/completion efficiency important factors

Poor producers 34-02, 34-01X and 34-25 short production life, depletion, ? completion/engineering issues



Two Medicine Cut Bank Sand Unit (TMCBSU)



Summary

Lower Cut Bank - High Remaining Potential

LCB Top producers associated with higher structural locations and greater reservoir thickness and quality, net sand pay >25 ft, porosity >0.11

No LCB OWC observed

Numerous infill locations from geological standpoint

Upper Cut Bank - Possible secondary target



Two Medicine Cut Bank Sand Unit (TMCBSU)

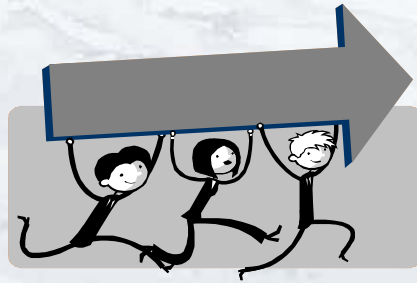


Deliverables – Phase 3

- Structural maps of upper and lower Cut Bank sand units
- Gross sand thickness maps of upper and lower Cut Bank sand units
- Net sand thickness maps of upper and lower Cut Bank sand units
- Net Pay thickness map of lower Cut Bank sand unit
- Summary presentation in Powerpoint
- 3-D Petrel model
- Digital log files



The Way Forward



Proposed Next Steps

➤ Geological Evaluation

- Integrate geological, production, injection and field data for well location selection
- Estimate Lower Cut Bank volumetric OOIP using Static Model

➤ Reservoir Simulation

- Perform Numerical Simulation and additional Production Analysis for waterflood evaluation, fracture analysis, reserve calculation, etc. concurrent with field data acquisition program

➤ Field Development Planning

- Recommend drilling, logging and formation testing plans for both Cut Bank and Baaken in new wells
- Collaborate on field development strategies
 - Infill Drilling with Pressure Maintenance
 - Waterflood Reinstallation



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Lower Cut Bank OOIP

Validation of OOIP using current Petrel geological model

- OOIP & Reserves Estimates: OOIP: 627 bbls/acre-ft ⇒ **105,390 Mbbbls**
 - Primary RF: 7.7% (48 bbls/acre-ft) ⇒ 8,068 Mbbbls
 - Secondary RF: 26% (164 bbls/acre-ft) (w/water flood): ⇒ 27,567 Mbbbls
- TMCBSU Cumulative Production of 10.48 MM bbls of oil estimated by SLB (2009) . (Approx. 10% Recovery) and Estimated Remaining OIP: **94.590 MM bbls of oil**
- Reactivation of waterflood could yield an additional 16 -17 MM bbls of oil
- Decline curve analysis of 71 wells suggested a potential recovery of 250,000 bbls – 555,000 bbls.
- Gustavson (2008) estimated 292,109 bbls net reserves from 30 wells (PDP, PDNP and PUD)

**Reference: BLM Report 1996, Gustavson 2008, Arkanova 2008 Annual Report, & Schlumberger 2009*



Two Medicine Cut Bank Sand Unit (TMCBSU)



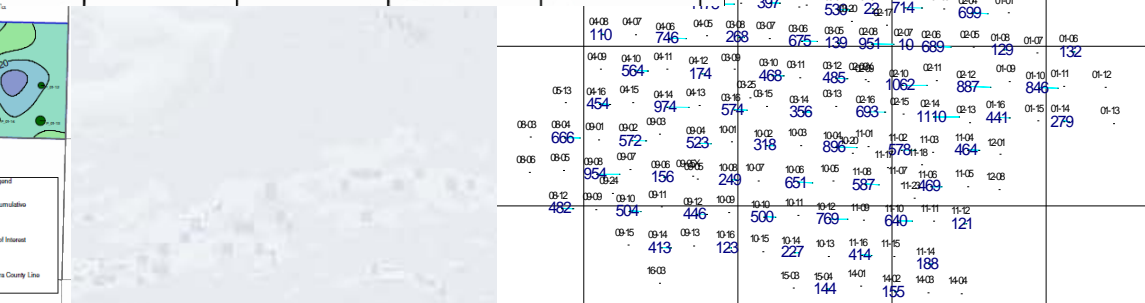
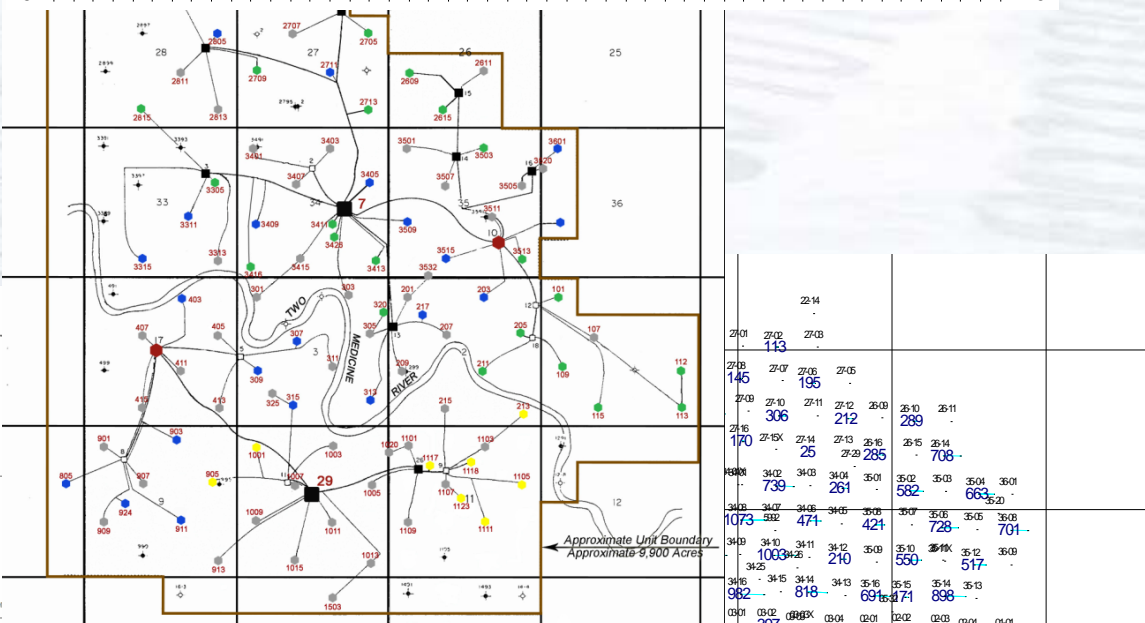
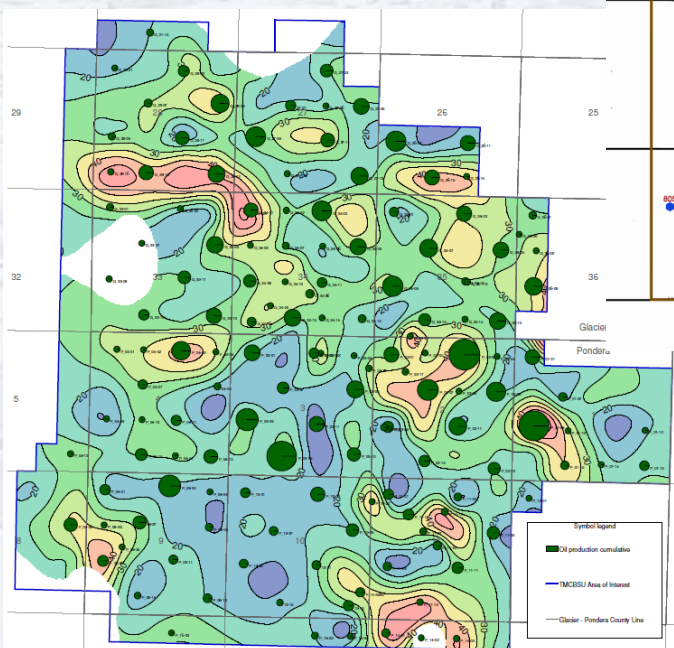
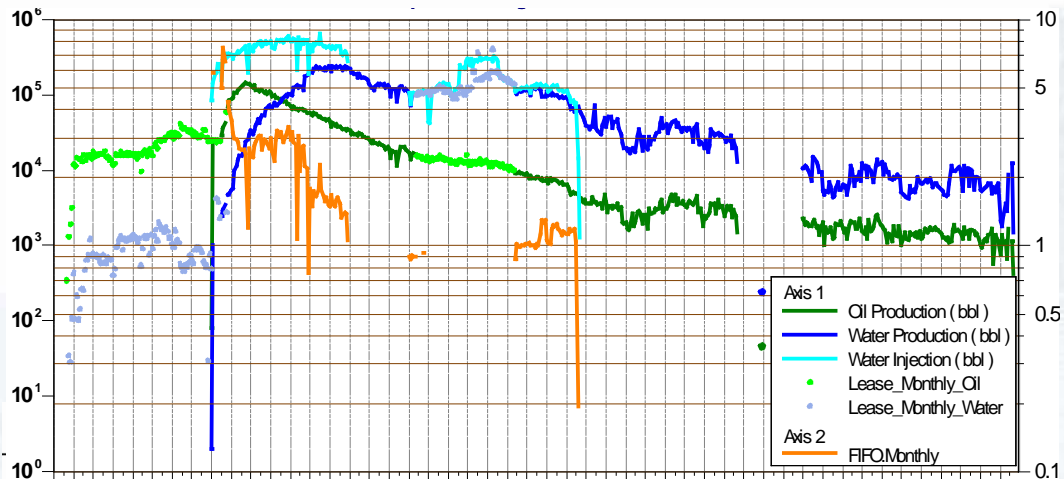
Integration:

Geology

Production

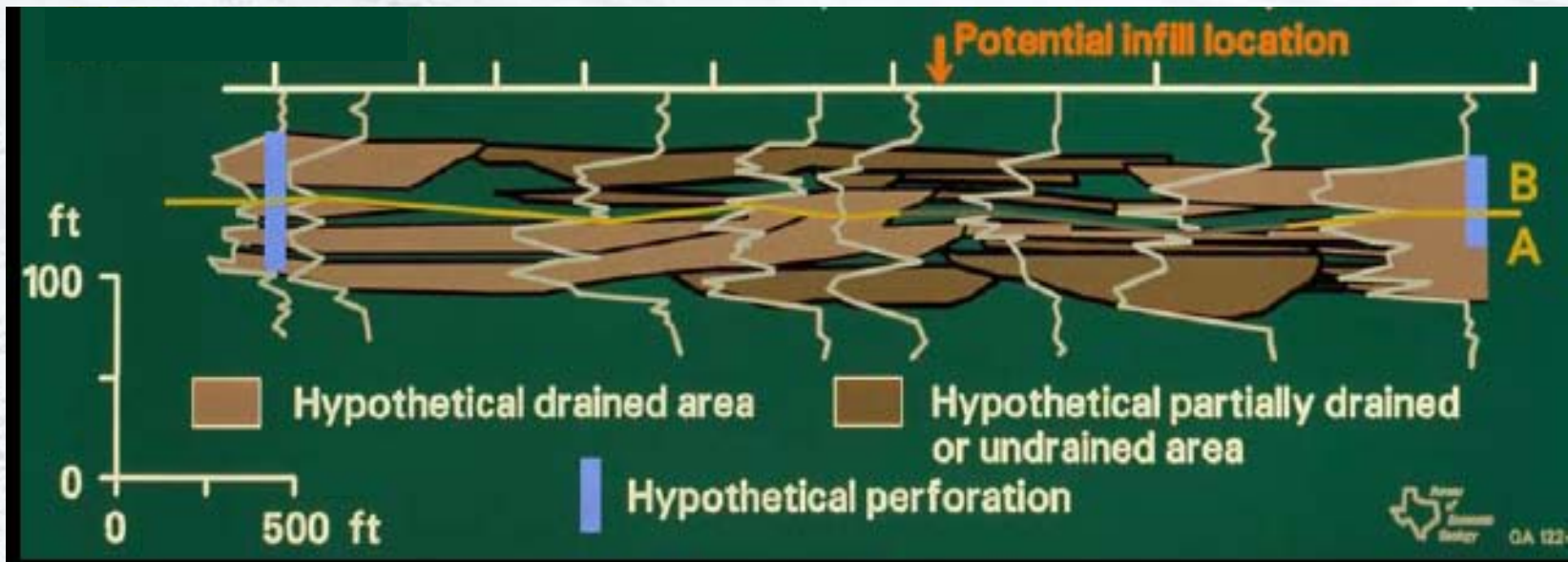
Waterflood

Field History



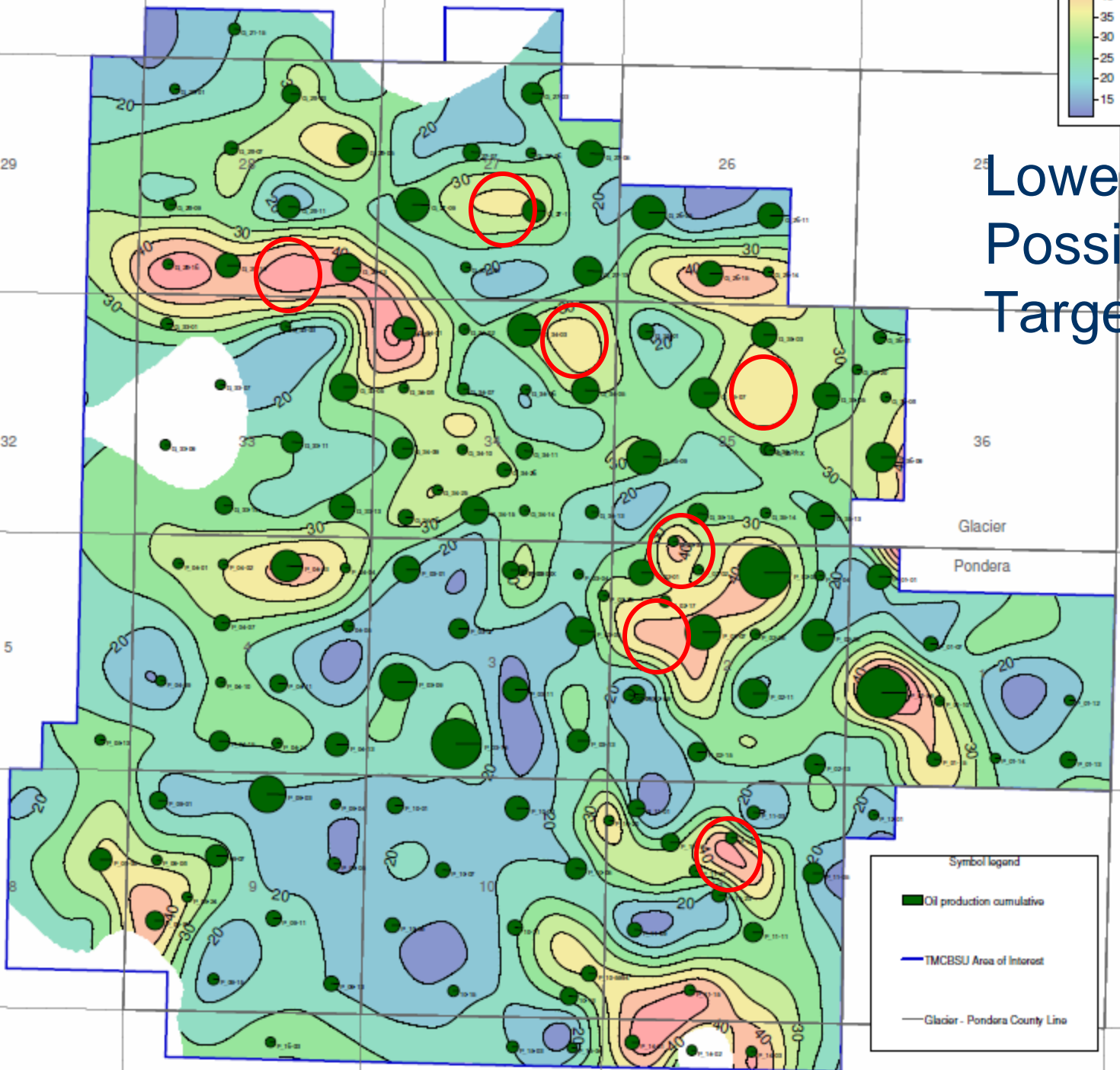
Infill Drilling Locations

Selection of new well locations in areas of good reservoir quality and structural position with remaining unswept potential.



after Jackson et al. (1988)

Lower Cut Bank Possible Infill Targets



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Next Phase - OOIP & Well Locations

- Geological Evaluation – Follow on to Phase 3 Mapping
 - Lower Cut Bank volumetric OOIP estimate using Static Model – 1 week (geologist)
 - Integrate geological, production, injection and field data to select new well locations – 3 to 4 weeks (geologist and production engineer)
 - Recommendations on infill vertical wells for 2010 drill locations
 - Completion by end March.



Thank You

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