In the Deep Subsurface of the San Joaquin Valley, are the Monterey, Kreyenhagen and Moreno Formations Continuous Oil Accumulations Analogous to the Bakken Formation?*

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Search and Discovery Article #11089 (2018)**
Posted June 25, 2018

*Adapted from oral presentation given at 2018 Pacific Section AAPG Convention, Bakersfield, California, April 22-25, 2018

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Abstract

Continuous oil accumulations are pervasive throughout large areas and are not affected by natural hydrodynamic influences. Three source rocks in the San Joaquin Valley are actively producing hydrocarbons and represent potential continuous oil accumulations: the Monterey, Kreyenhagen and Moreno formations. In 2014, the Energy Information Administration (EIA) announced that there are potentially 15 BB of recoverable oil in the Monterey Formation in California, spiking huge interest. Such a resource would make the Monterey by far the largest continuous oil accumulation in North America. This number has since been reduced dramatically to 600 MMBO for the state and 21 MMBO within the San Joaquin Valley. In this study, first the concept of the continuous oil accumulation is reviewed, and differentiated from other non-conventional resources. Next, the subsurface character of the Bakken Formation of North Dakota is compared with the three source rocks in the San Joaquin Valley at oil window depths. To characterize these reservoirs, hundreds of well logs, core descriptions, and mud logs were studied. A technique to rank character of oil show data was developed in which Interesting, Possibly Interesting, or Not Interesting wells were located on thermal maturity maps. Interesting wells have significant oil shows, whereas Not Interesting wells show minor or no shows.

In the Bakken Formation, the character of the oil show correlates with well productivity. Applying this same classification to the San Joaquin Valley source rocks leads to a more disappointing conclusion. Although there are oil shows in the source rocks of the San Joaquin Valley at oil window depths suggesting the presence of a continuous oil accumulation, the distribution of shows is both laterally and vertically heterogeneous and not predictable. Moreover, recent attempts to produce from source rocks at these depths have not been economically successful. We conclude that the three source rocks in the San Joaquin Valley represent heterogeneous and discontinuous oil accumulations at oil window depths in the subsurface. Likely there are billions of barrels of oil in these discontinuous oil accumulations. Source rocks in the Bakken are rated as world class: source rocks in the San Joaquin Valley are good to excellent quality. However, the quality of the oil shows in the San Joaquin Valley appears more discontinuous than the Bakken Formation. It is possible that effective drainage between the source rocks and the up-dip reservoirs has left large volumes of the source rocks at oil window depths with only residual oil saturation. Complex structural

and stratigraphic architecture, heterogeneity and continuity create issues of predictability for optimal areas to target. Rapid rates of subsidence over the past few million years and accompanying thrusting and folding resulted in a complex subsurface pressure regime. The lack of clear hydraulic fracture targets, analogous to the middle Bakken, further complicates drilling decisions, and likely deliverability. In addition, the oil windows in the San Joaquin Valley are significantly deeper than the Bakken Formation which would result in substantially higher well cost. Recent drilling results support this study and suggest that heterogeneous and discontinuous oil accumulations in the San Joaquin are unlikely to become economic without dramatic changes in technology.

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In the Deep Subsurface of the San Joaquin Valley,
are the
Monterey, Kreyenhagen and Moreno Formations
Continuous Oil Accumulations
Analogous to the Bakken Formation?

$$$ A Billion Dollar Question $$$$

Dave Larue, retired

Mark Mercer, retired

Mark Smithard, Cantium LLC

Note: this presentation is based on our paper published in the AAPG Bulletin

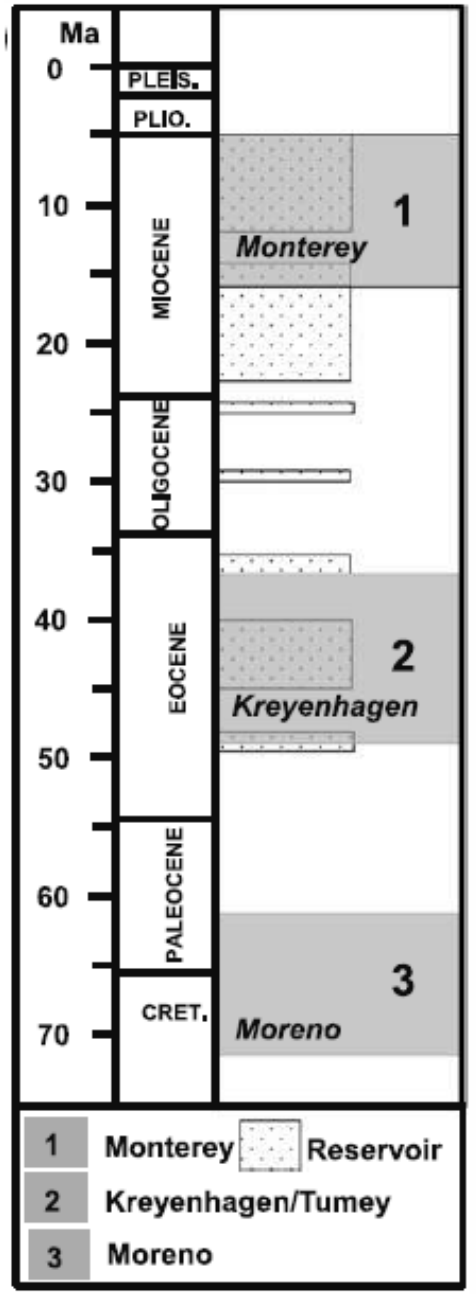
Three deep resource plays in the San Joaquin Valley compared with the Bakken Formation

D. K. Larue, M. Smithard, and M. Mercer

AAPG Bulletin, v. 102, no. 2 (February 2018), pp. 195–243

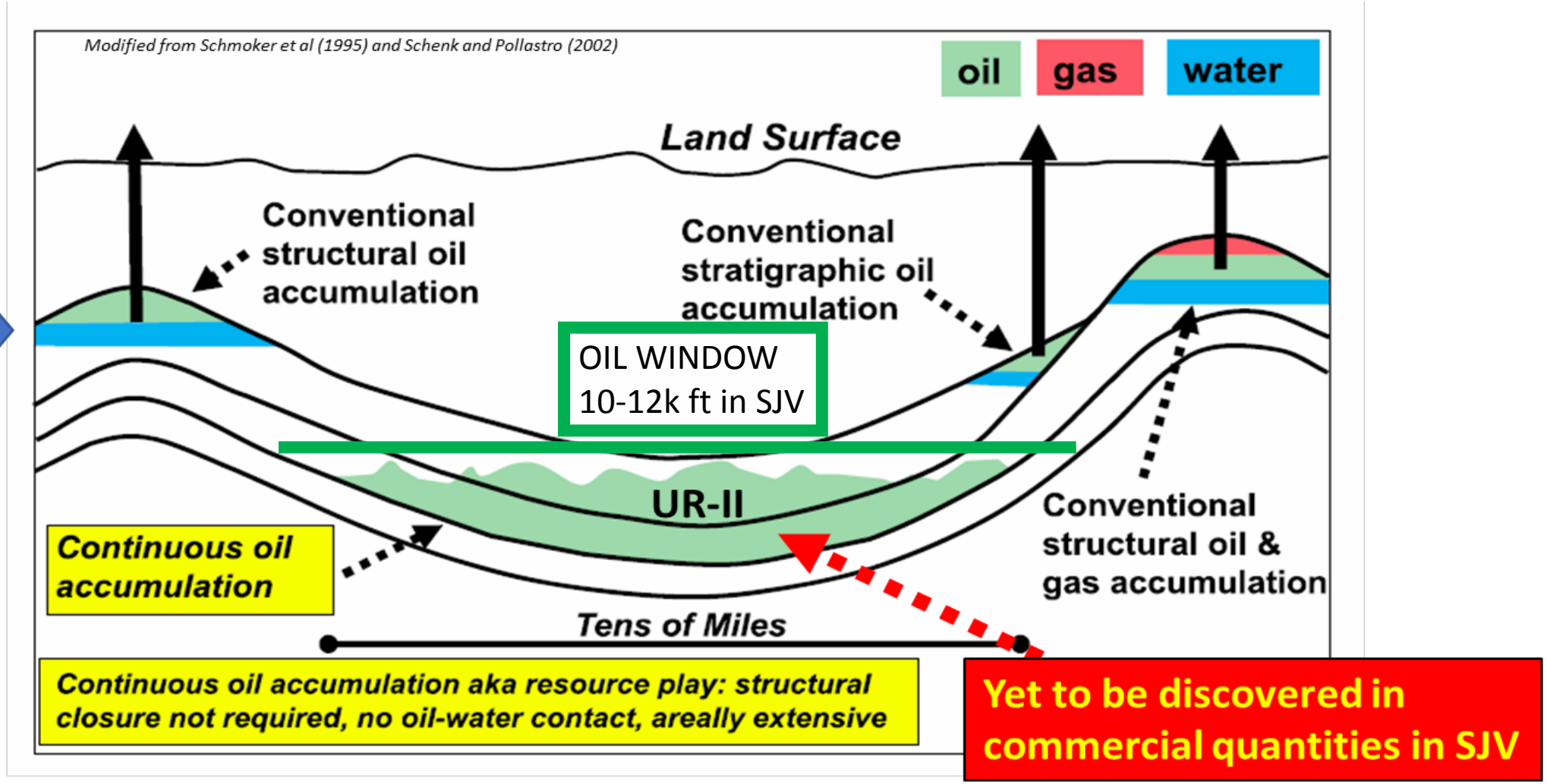
Theme

- The Monterey Formation is a known source rock in the San Joaquin Valley locally >10,000 ft thick and actively creating oil in the deep subsurface
  - Isn't all that source rock valuable?
  - Can't we do anything with it?
  - And then there's the Kreyenhagen and Moreno Formation source rocks that are actively creating oil in the deep subsurface
- ***Don't we have a potential unconventional play here worth billions of dollars?***
  - ***Hint: the answer is "yes"***
- ***Is it producible?***
  - ***Maybe? Some day?***
- ***What's missing?***
  - ***We don't know… yet***

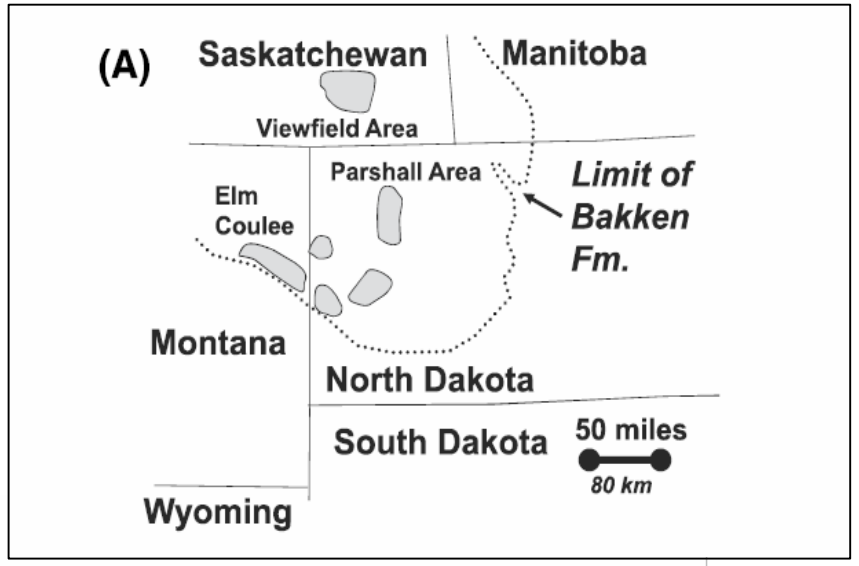


Simplified stratigraphic column after Hosford Scheirer and Magoon, 2007

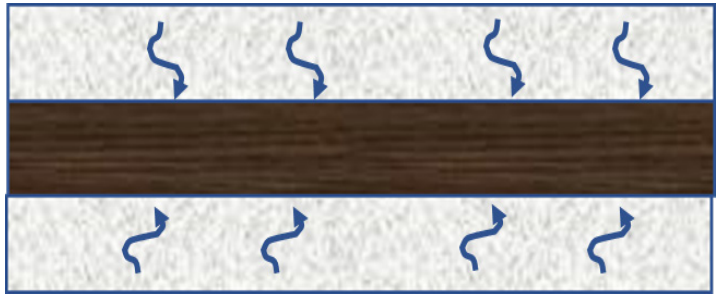
Unconventional Reservoirs: Application to the San Joaquin Valley

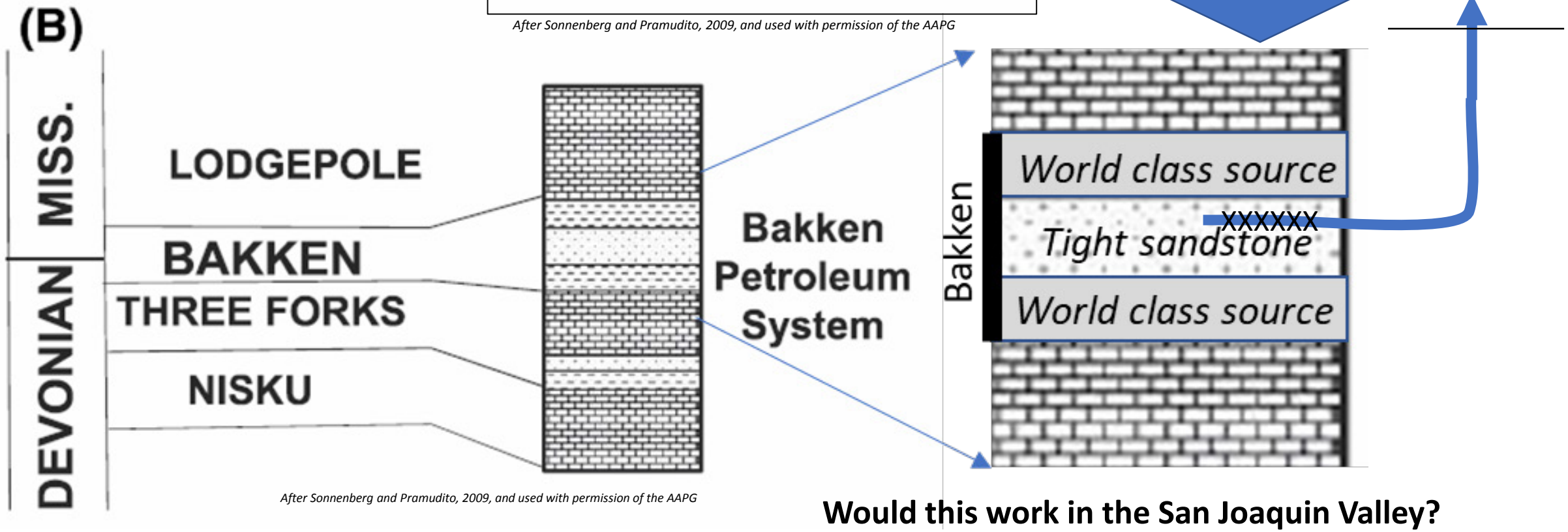


Let's Talk About the Bakken Formation... *The Type Example of Continuous Oil Accumulation*



After Sonnenberg and Pramudito, 2009, and used with permission of the AAPG



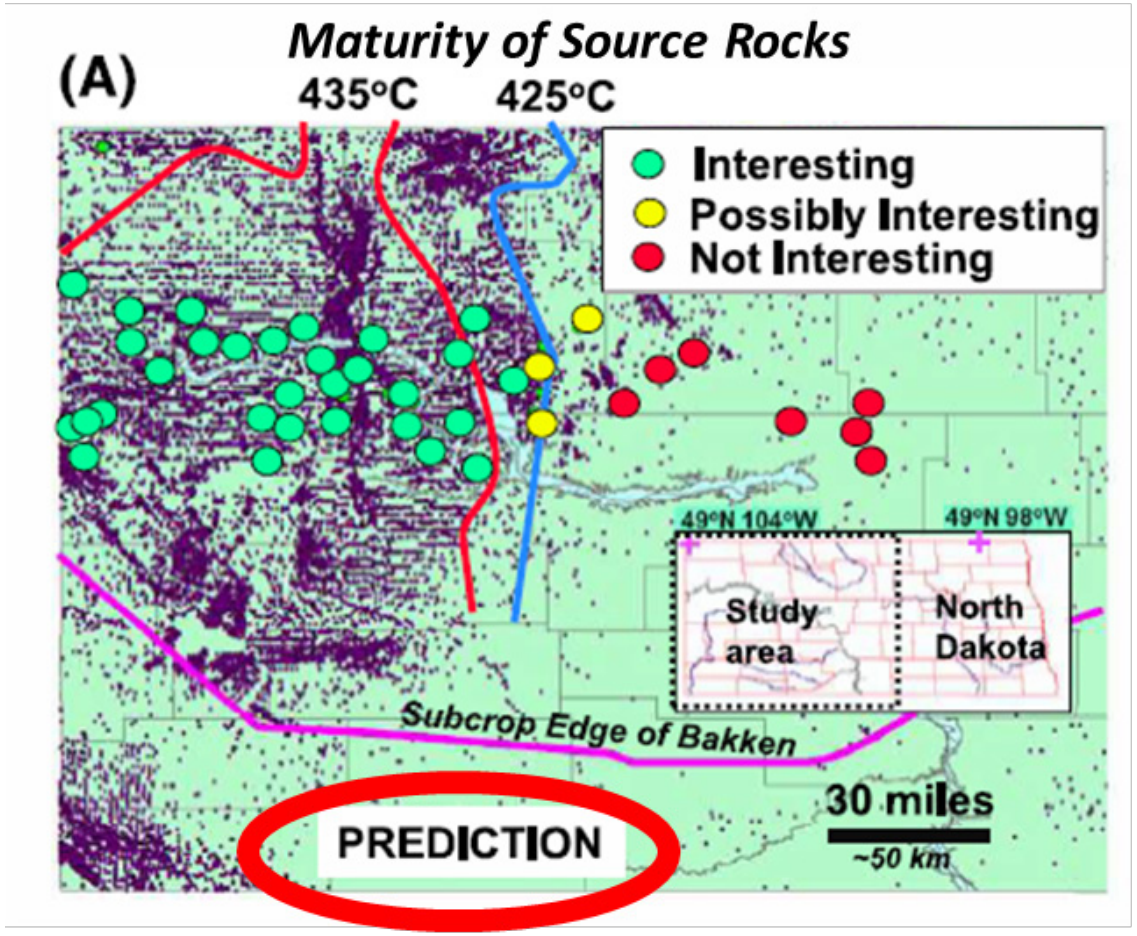


After Sonnenberg and Pramudito, 2009, and used with permission of the AAPG

Would this work in the San Joaquin Valley?

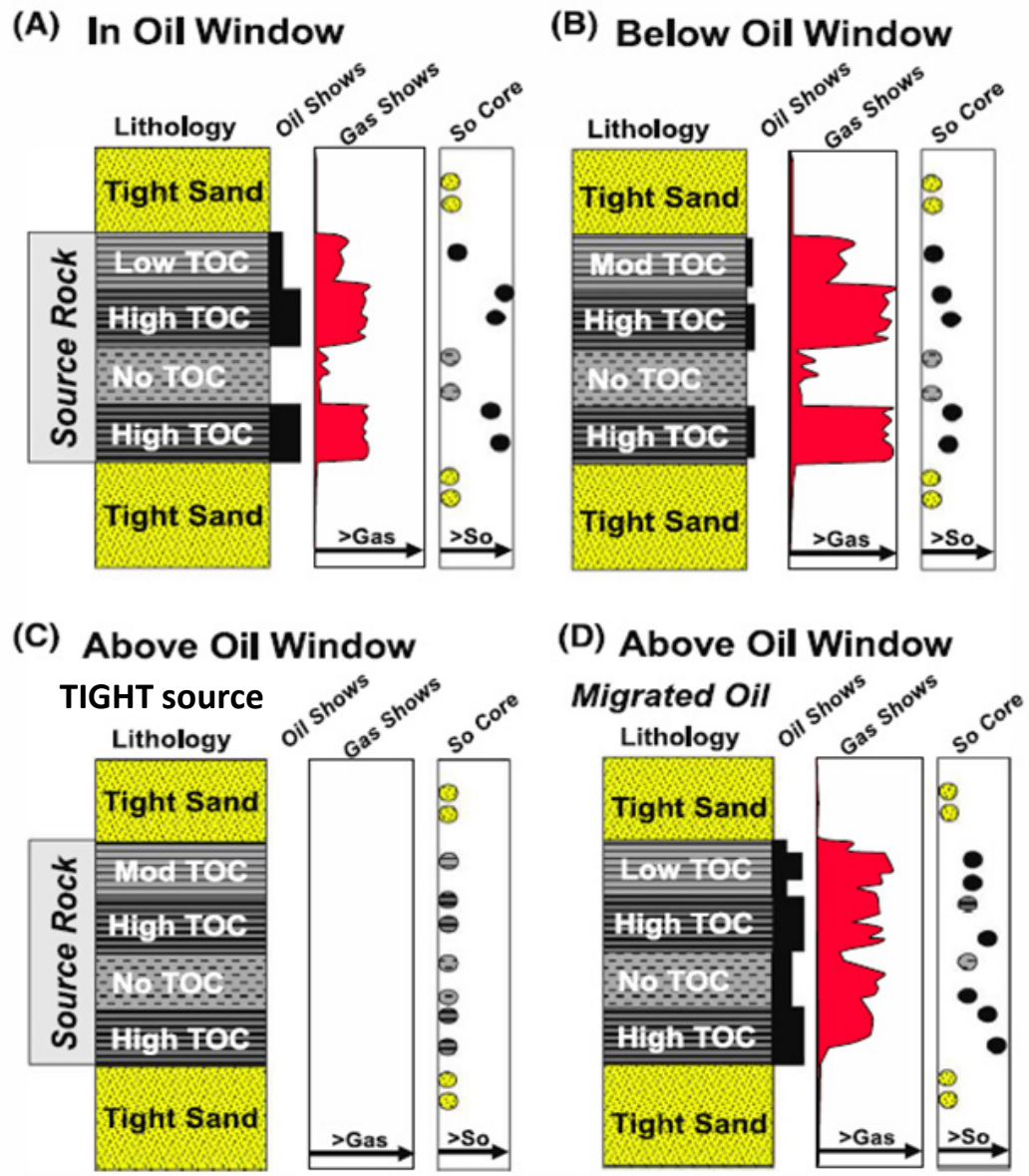
Characterizing the Bakken-Type Play

Predicted Behavior Based On

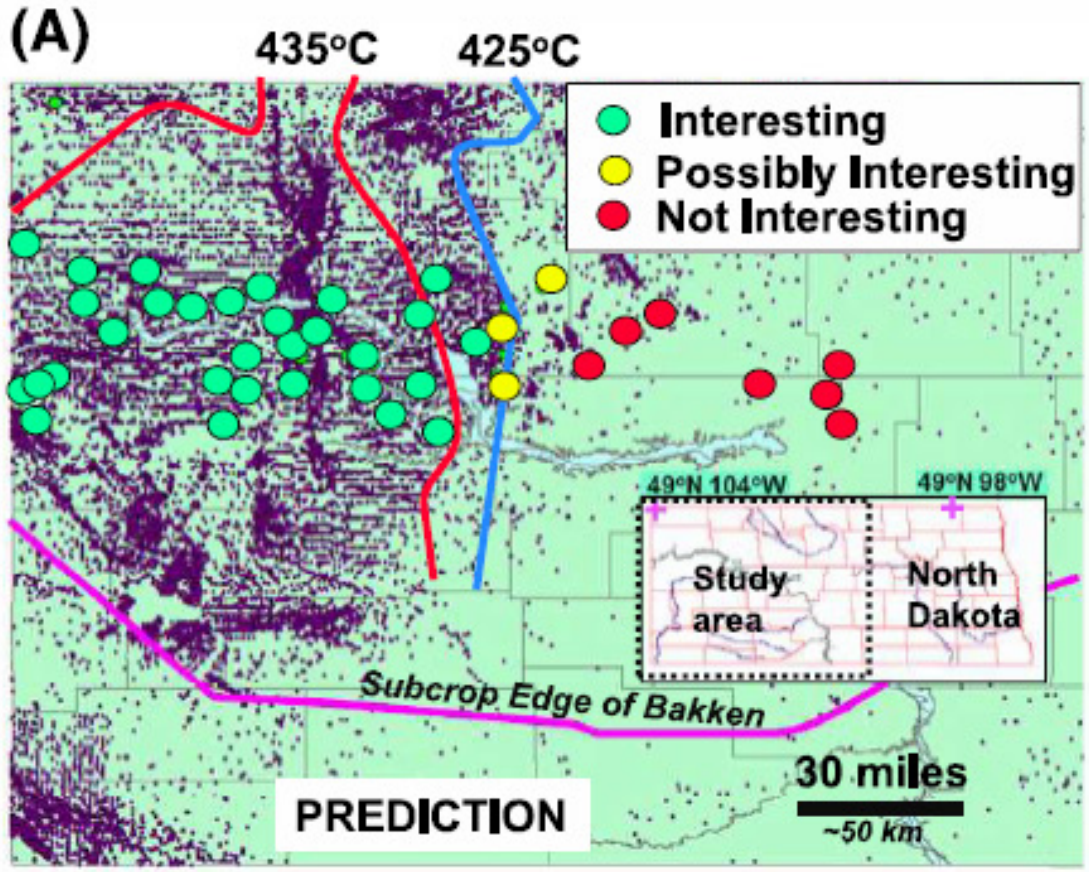


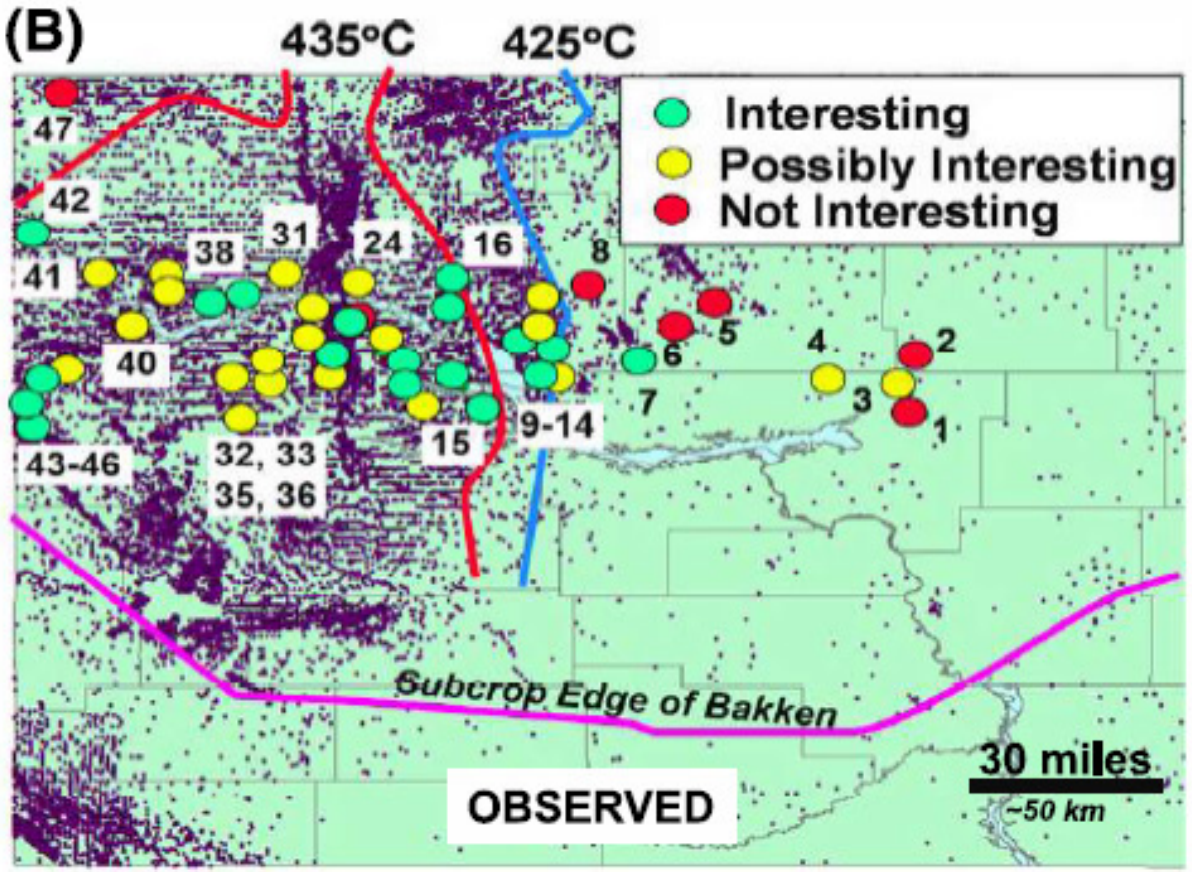
Base map after Sonnenberg, 2011

Recognizing UR-II in the Subsurface



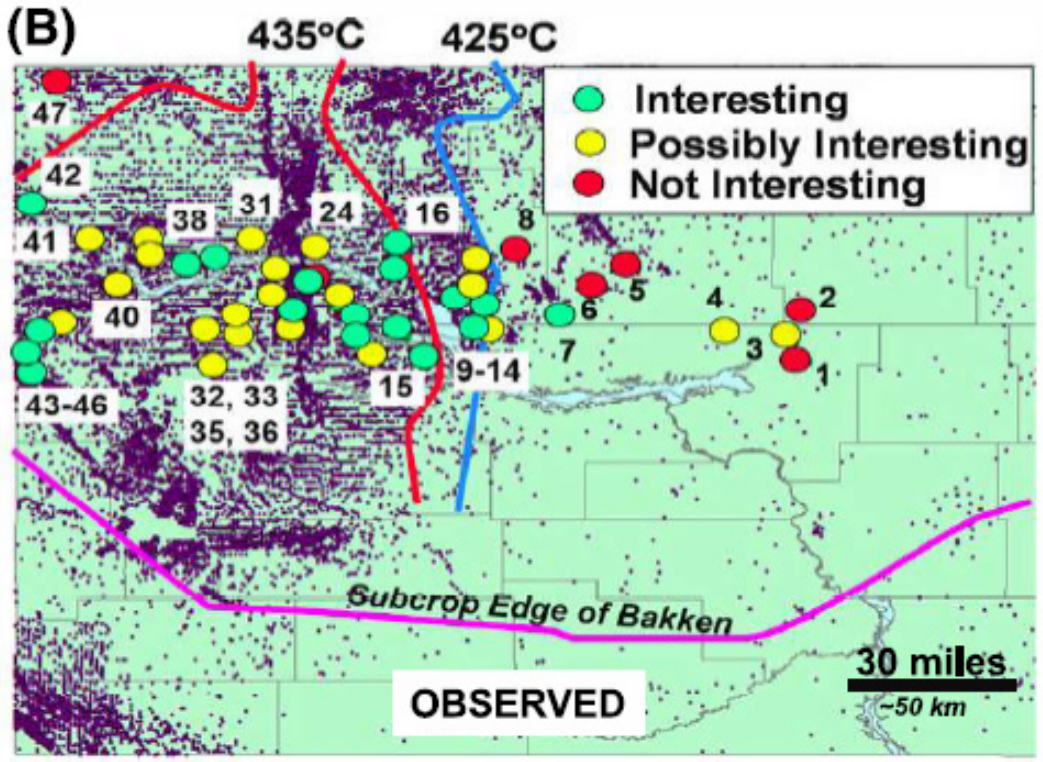
BAKKEN





Base map after Sonnenberg, 2011

Well Observations



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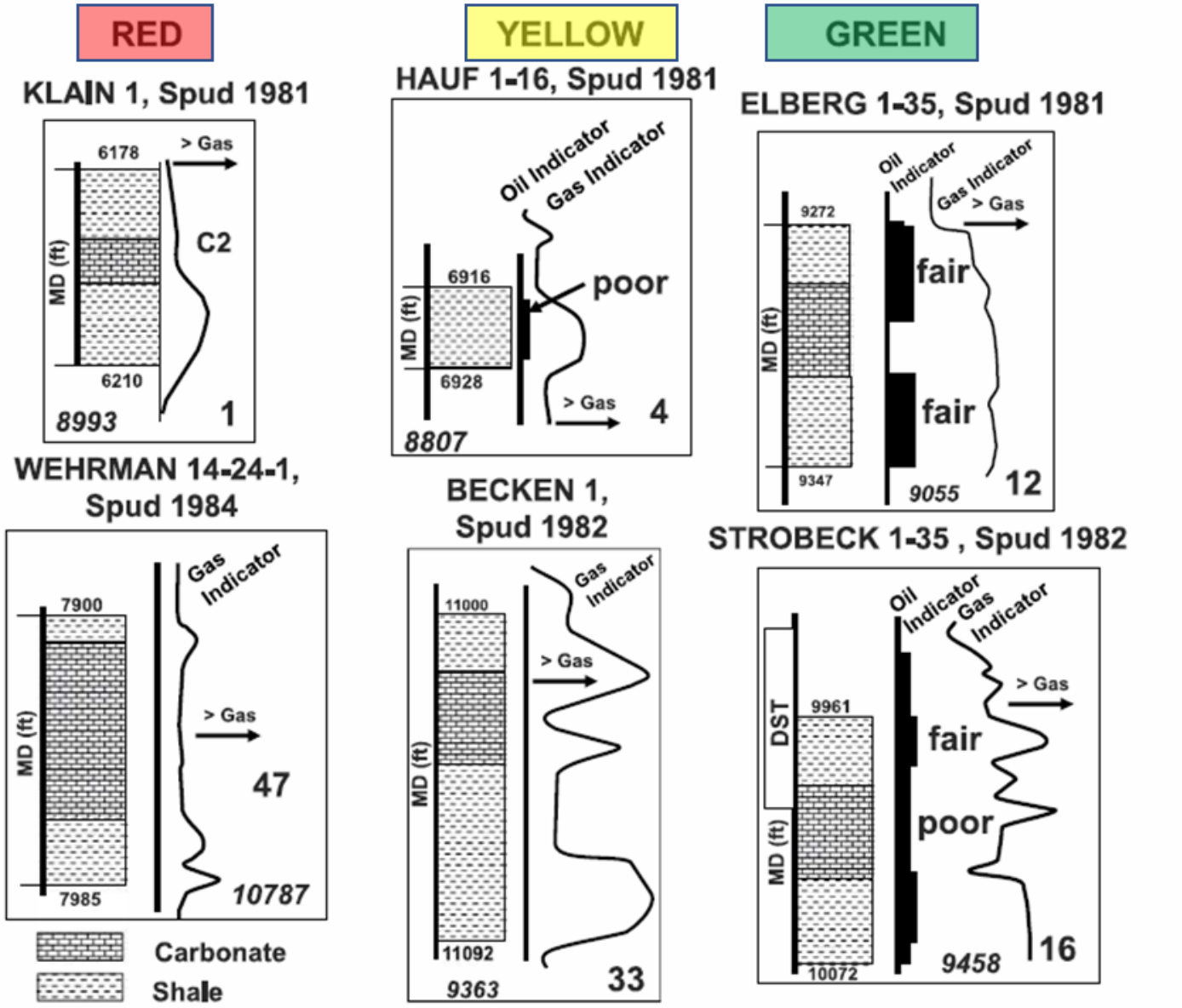
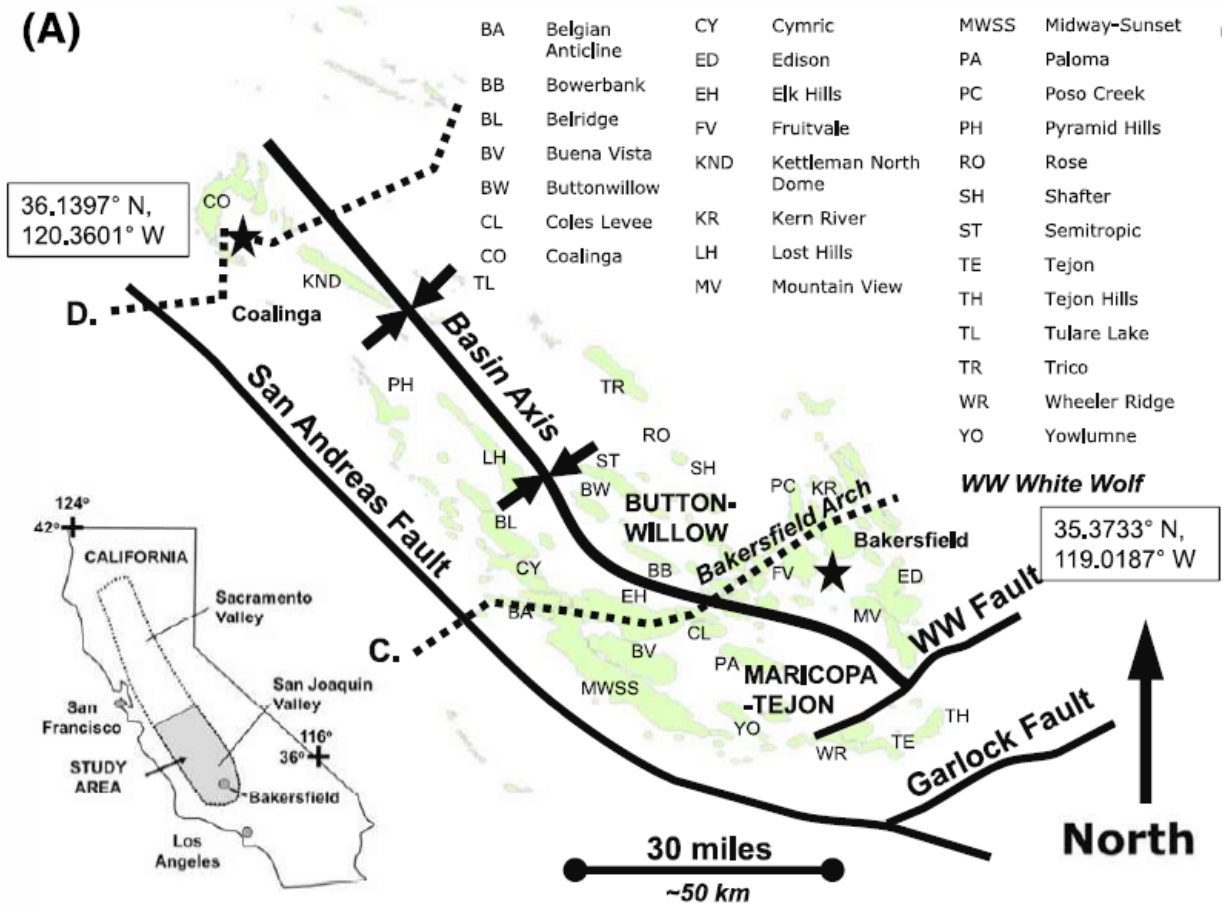
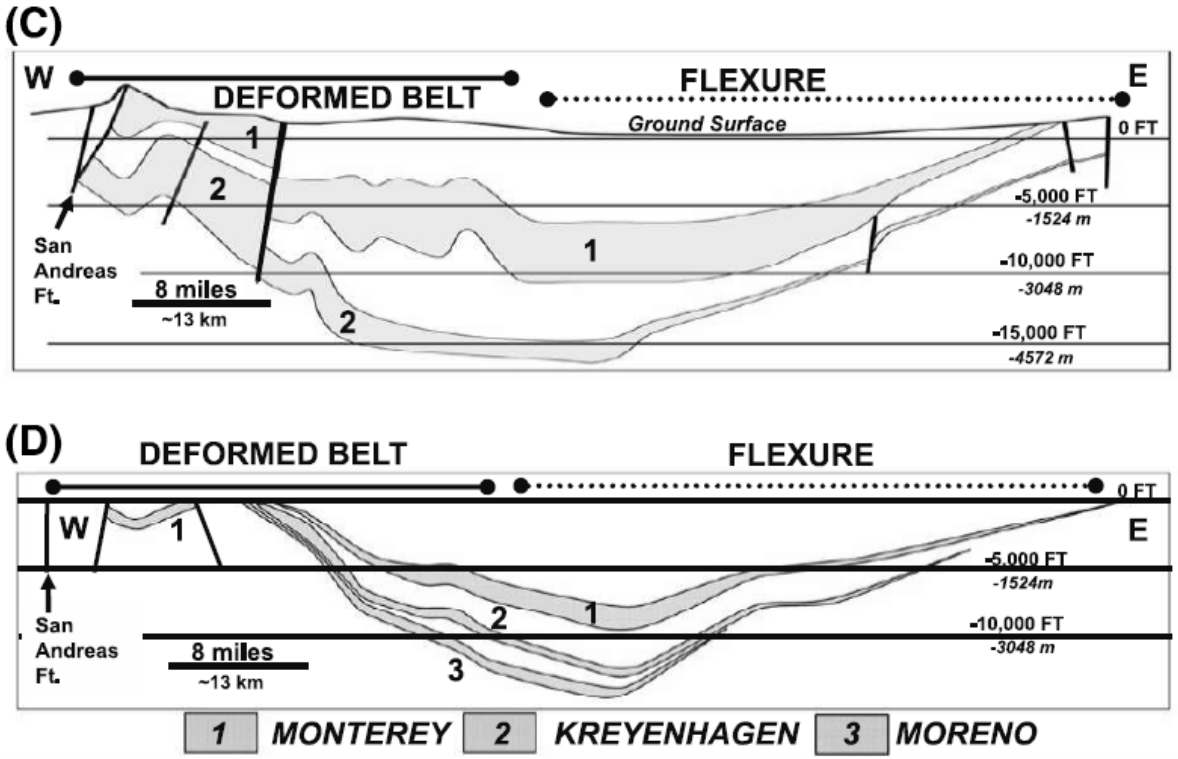


well data from the North Dakota geological survey

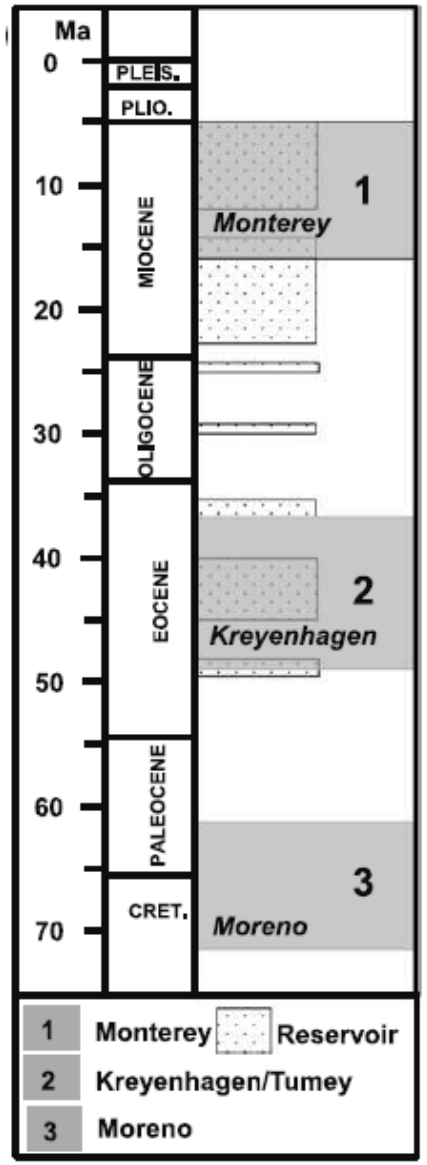
San Joaquin Valley





Cross sections after Church et al, 1957, with permission of the AAPG

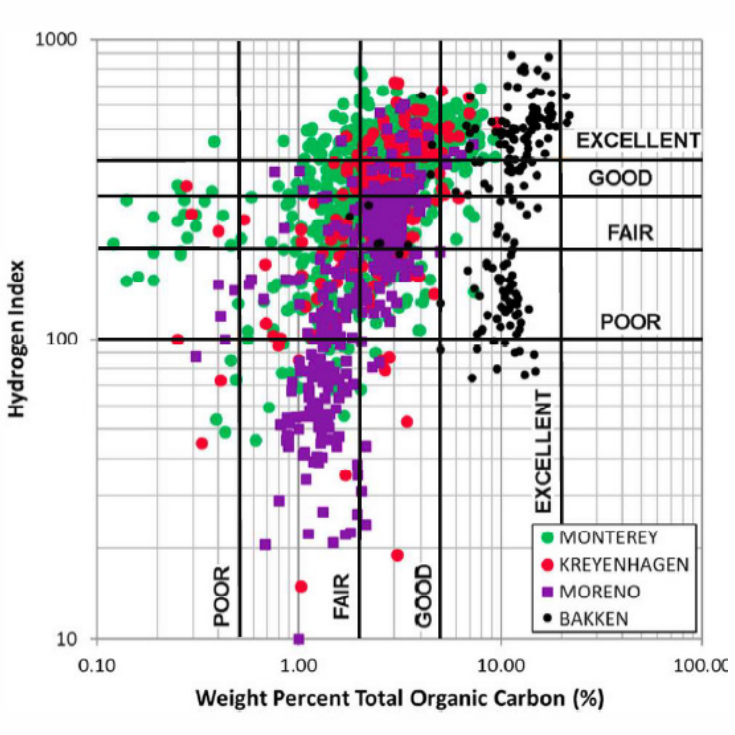
Overview of Source Rocks



Simplified stratigraphic column after Hosford Scheirer and Magoon, 2007

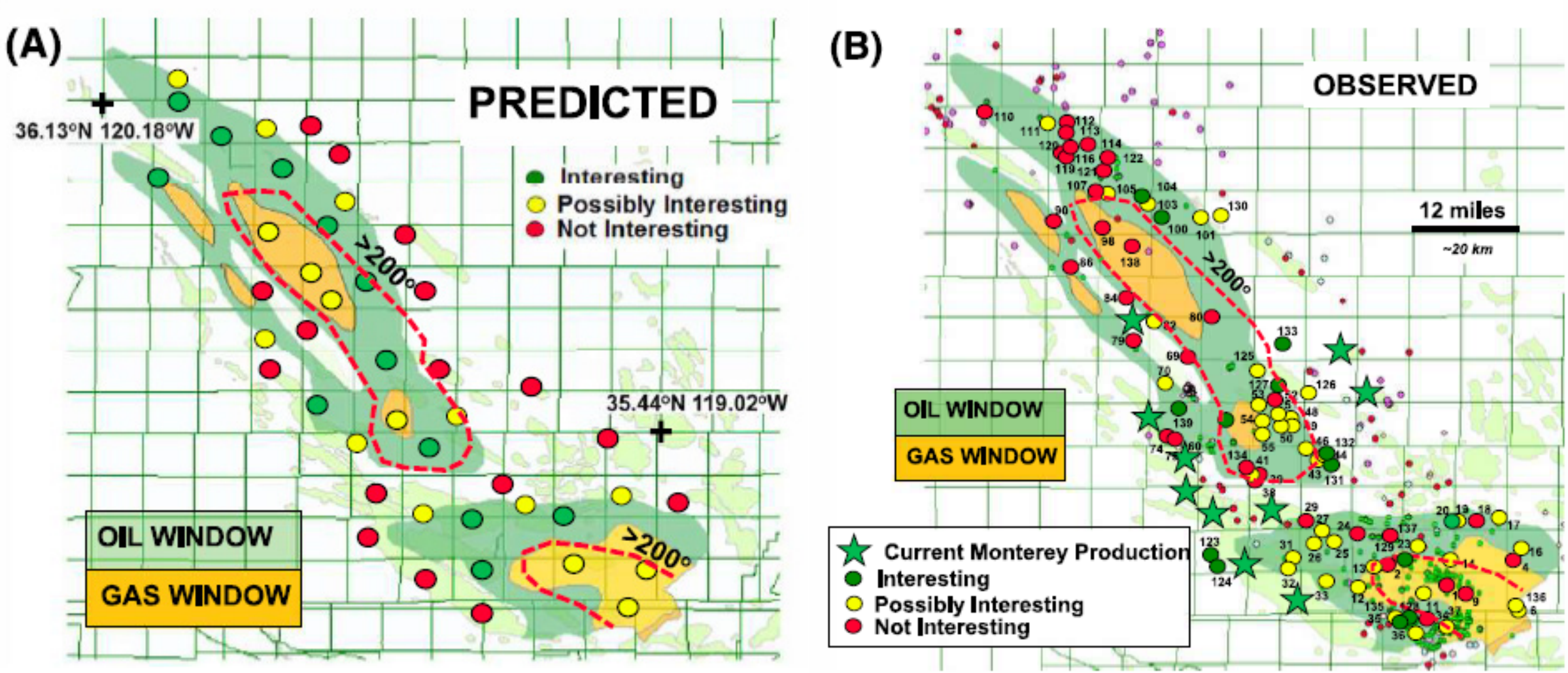
In general:

- Bakken is a world class source rock, mature at depths below about 7500-9500 ft
- The Monterey and Kreyenhagen Formations are very good source rocks, and the Moreno is slightly worse. Depths to maturity are likely below 12,000 ft.



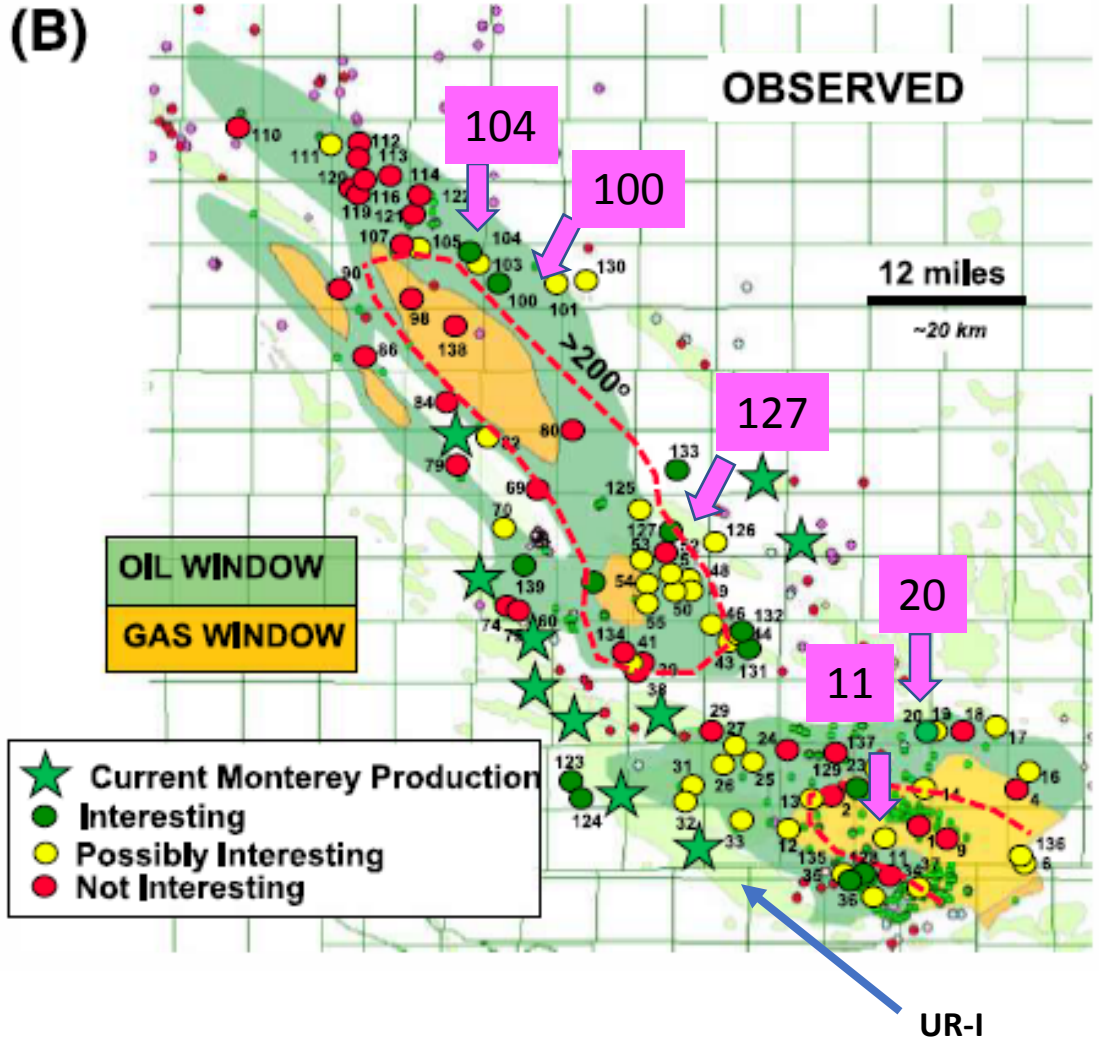
Data from California are largely from Peters et al (2007), and data for North Dakota are from Price et al (1984)

Monterey Formation

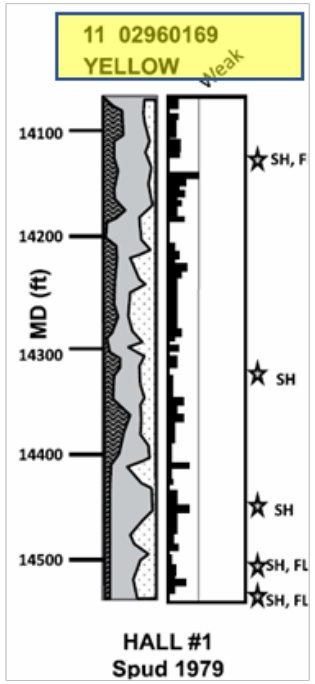


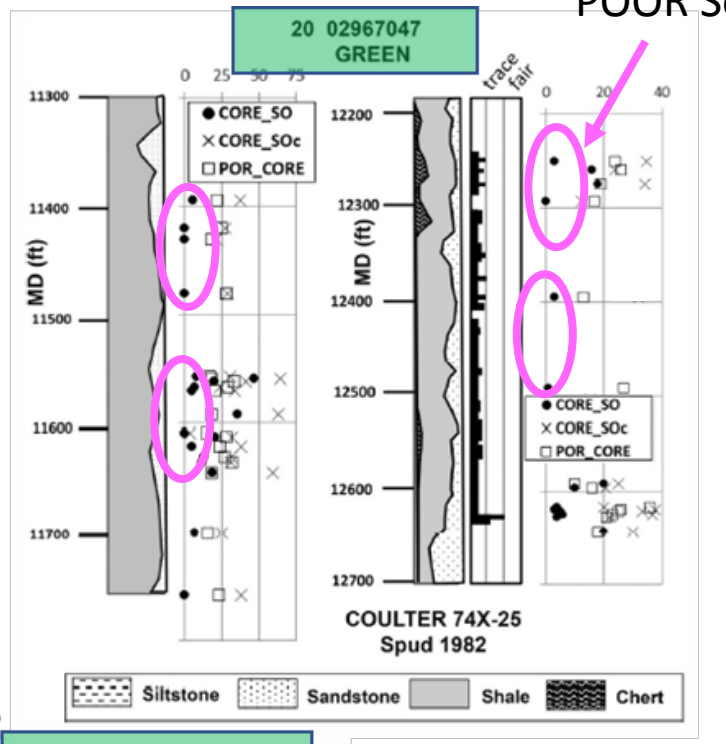
Base map after Peters et al, 2007

Well Observations



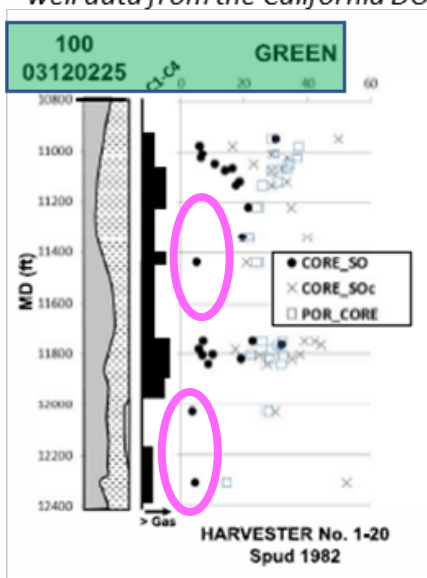
Base map after Peters et al, 2007

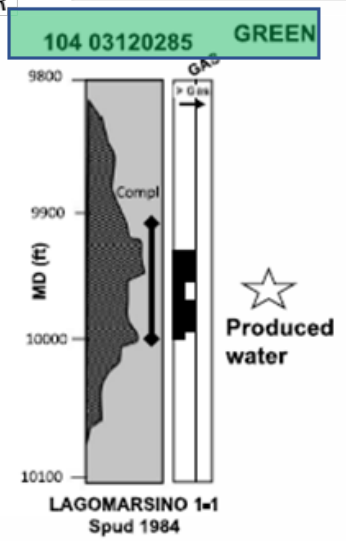




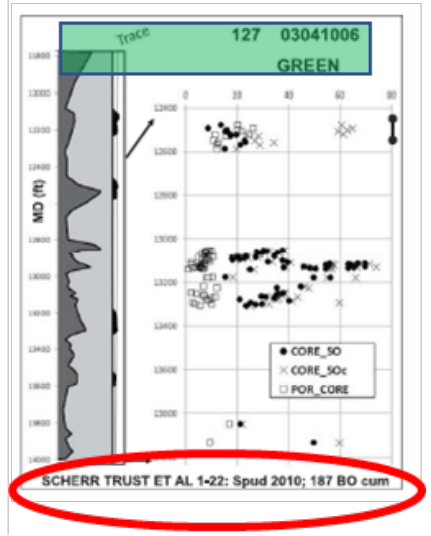
POOR So

well data from the California DOGGR



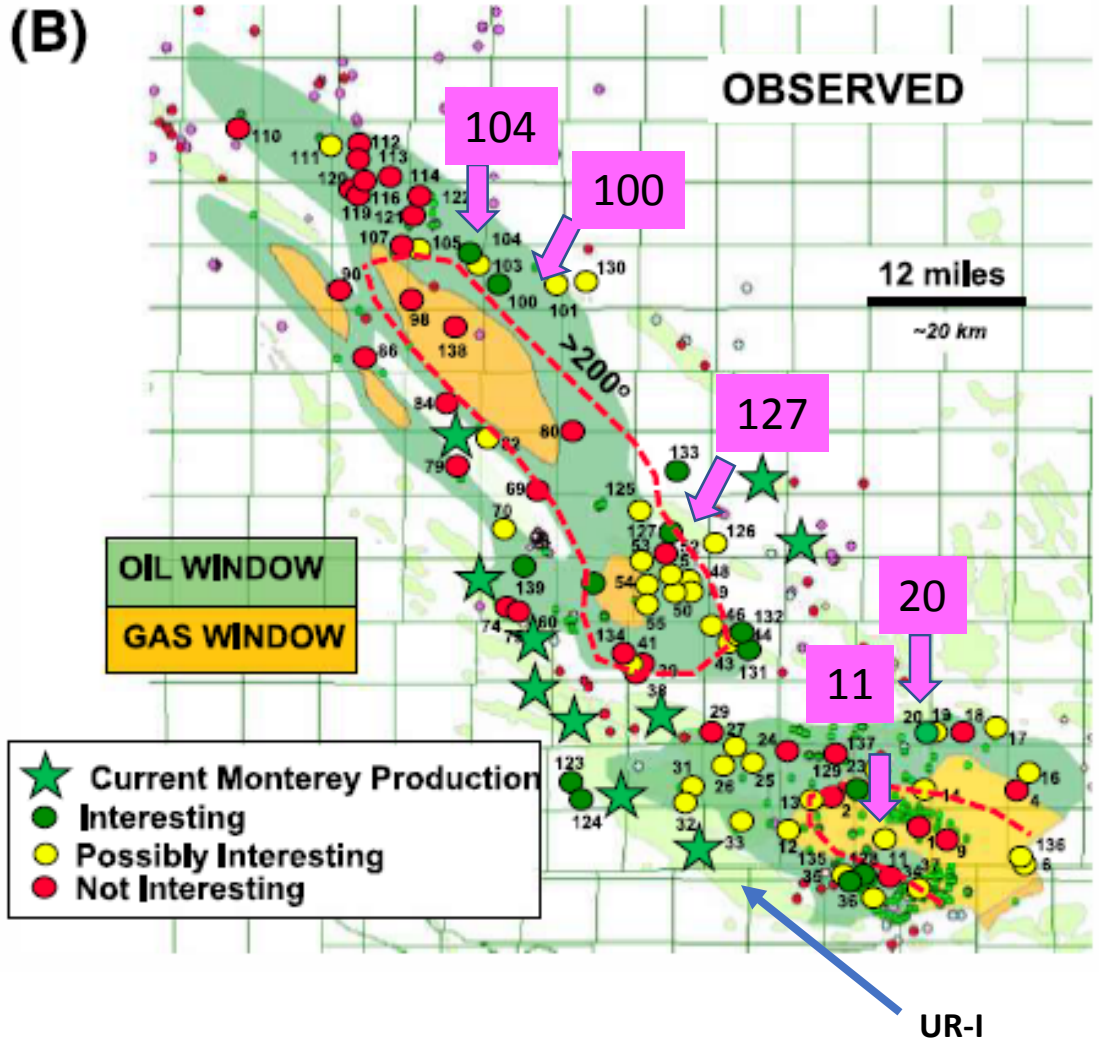


Produced water

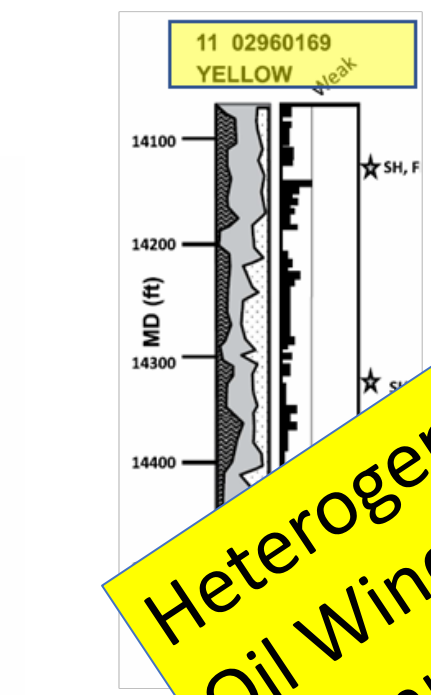


SCHERR TRUST ET AL 1-22: Spud 2010; 187 BO cum

Well Observations



Base map after Peters et al, 2007



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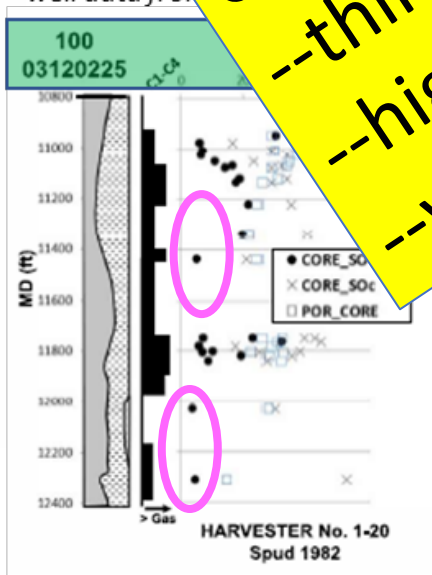
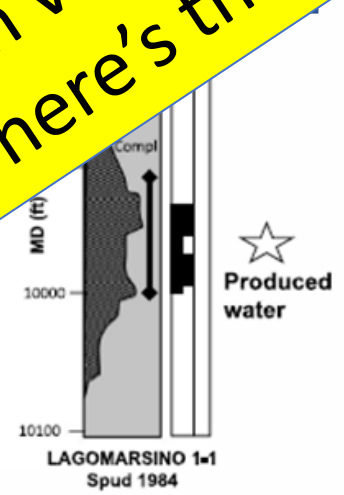
Heterogeneous Oil Shows in the Oil Window:
--thinner sweet zones
--high variability in So quality
--where's the frac target?

well data fro





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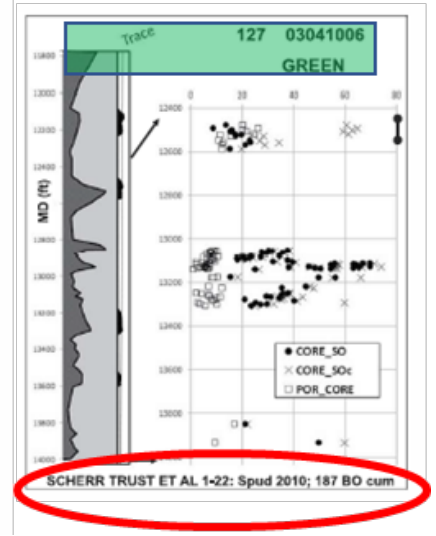
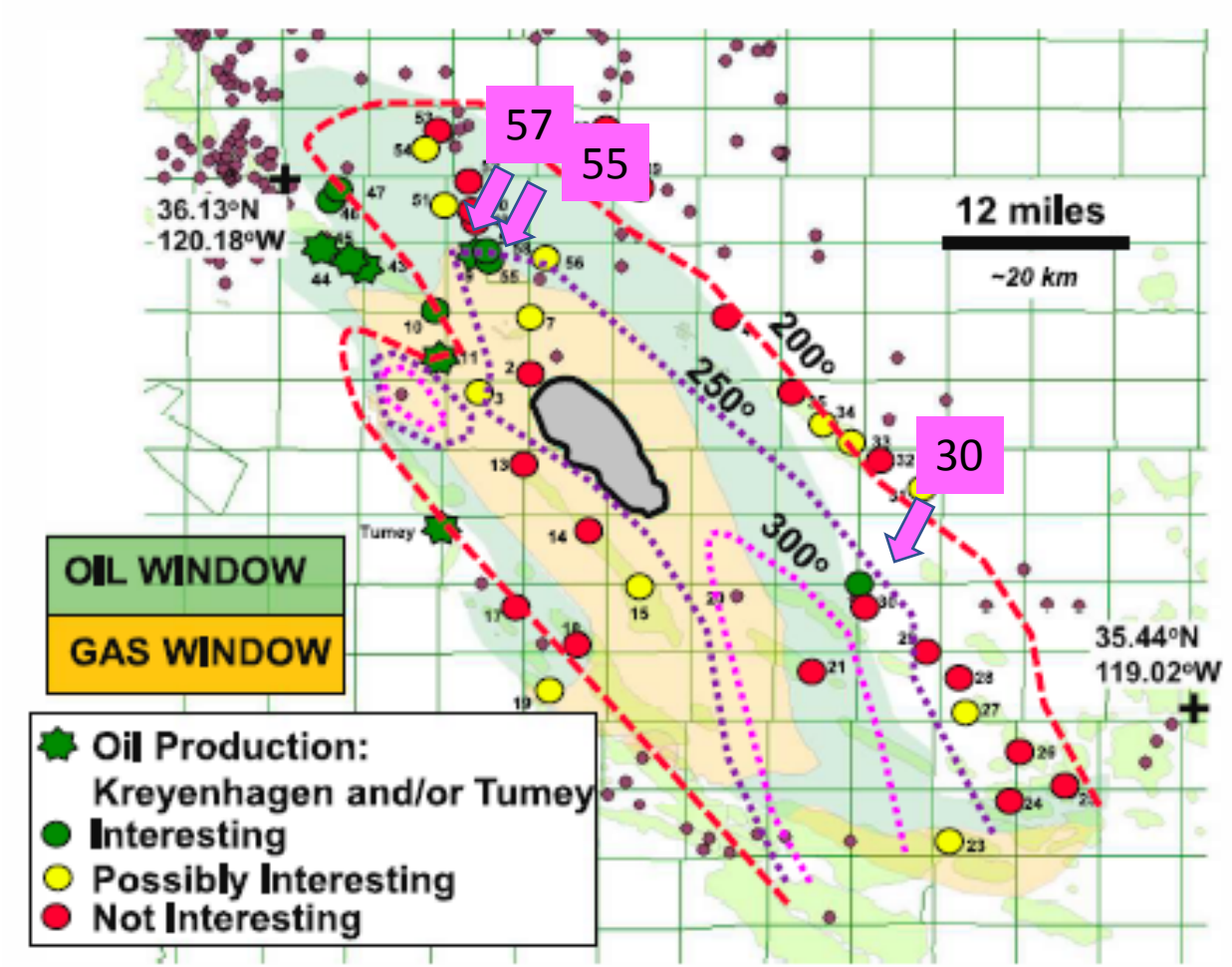
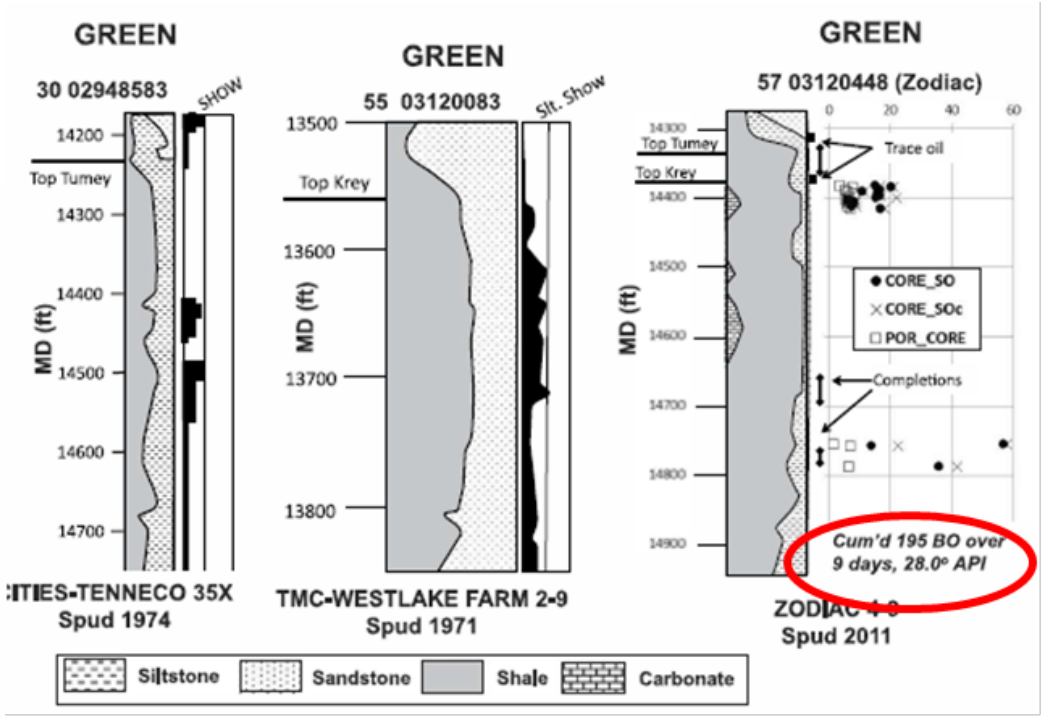


SCHERR TRUST ET AL 1-22: Spud 2010; 187 BO cum

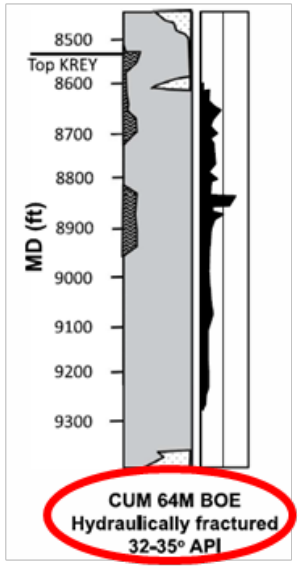
Kreyenhagen



Base map after Peters et al, 2007



well data from the California DOGGR



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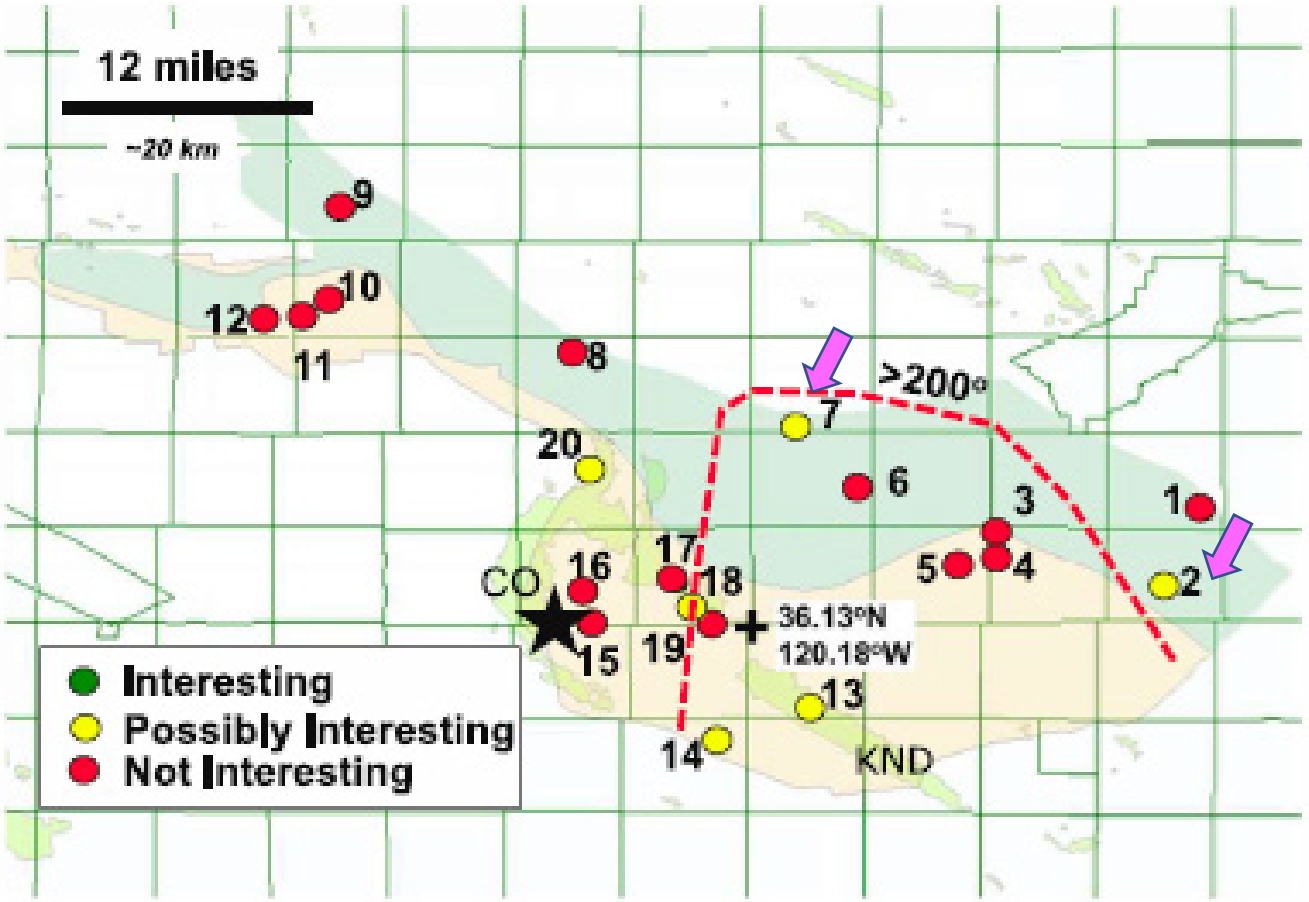
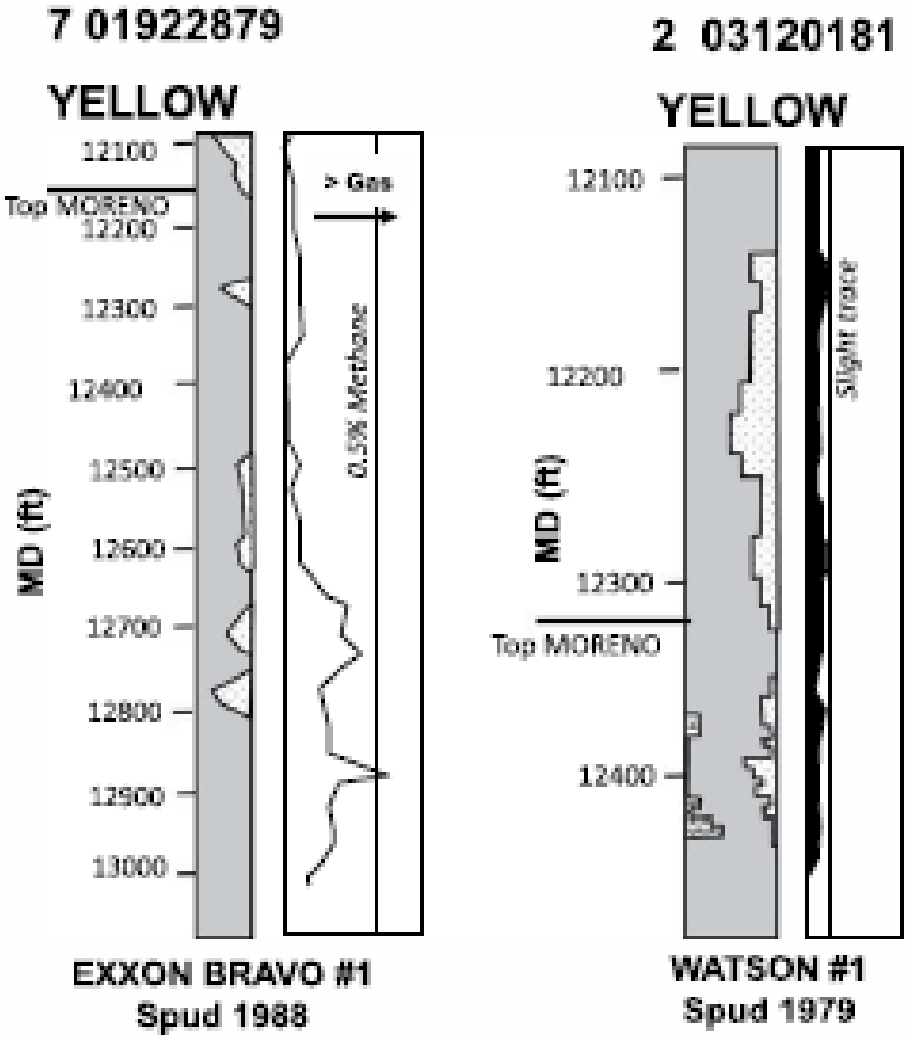
UR-I or UR-II?

Moreno





Base map after Peters et al, 2007

well data from the California DOGGR

Well	API	Field Name	Target Formation	Company	Date Drilled	Production Results	Comments
2-9H	03043150	Bowerbank	Monterey	Venoco	2011	30-day IP: 11 bopd API 32-37^{o} 80 MCF Cum Prod: <5000 BO	Lateral below 10,000 ft, ~4500 ft deviation. Weak shows. Hydraulic fractured.
TPJ Two #1	03120464	Exploratory NE of Trico	Monterey	Hess	2012	Not produced	TD 9686 ft
Paloma Deep #1	03036090	Paloma	Monterey	Neon	2011	Cum Prod <600 BO, <4000 MCF: API 23^{o} to API 36^{o}	Well plus two sidetracks: TD 10459 ft (3187 m), 11942 ft (3639 m) and 13320 (4059 m).
Scherr Trust et al 1-22	03041006	Semitropic	Monterey	Venoco	2010	<200 BO, no gas reported	TD 14015 ft
Pierce 1-31	03041005	Semitropic, Desert Prospect	Monterey	Venoco	2010	No oil, produced water	
Bullitt 1-7	03042124	Semitropic	Monterey	Venoco	2011	<500 BO Cum Prod. 26.3^{o} API	
BLM 1-29	03039795	Sevier Prospect	Monterey	Venoco	2011	<5000 BO Cum Prod, 30-36^{o} API	
BLM 4-19	03046156	Sevier Prospect	Monterey	Venoco	2012	19,190 BO Cum Prod 33-40^{o} API	Mud log oil shows: 6600 to 7800 ft
Thorndyke 882D-8	03047120	Exploratory north of Belridge	Monterey	Aera	2012	8,499 BO Cum Prod 26.3^{o} API	Monterey at 11337 ft, TD 17250 ft. Maximum production rate 150 bopd.
4-9	03120448	Kettleman City	Kreyenhagen	Zodiac	2010	<500 BO Cum Prod 28-33^{o} API	TD 14950 ft
1-10	03120449	Kettleman City	Kreyenhagen	Zodiac	2011	<3000 BO Cum Prod 29^{o} API	First hole, 15161ft , second 17550 ft

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Bullitt 1-7	03042124	Semitropic	Monterey	Venoco	2011	<500 BO Cum Prod. 26.3^{o} API	
BLM 1-29	03039795	Sevier Prospect	Monterey	Venoco	2011	<5000 BO Cum Prod, 30-36^{o} API	
BLM 4-19	03046156	Sevier Prospect	Monterey	Venoco	2012	19,190 BO Cum Prod 33-40^{o} API	Mud log oil shows: 6600 to 7800 ft
Thorndyke 882D-8	03047120	Exploratory north of Belridge	Monterey	Aera	2012	8,499 BO Cum Prod 26.3^{o} API	Monterey at 11337 ft, TD 17250 ft. Maximum production rate 150 bopd.
4-9	03120448	Kettleman City	Kreyenhagen	Zodiac	2010	<500 BO Cum Prod 28-33^{o} API	TD 14950 ft
1-10	03120449	Kettleman City	Kreyenhagen	Zodiac	2011	<3000 BO Cum Prod 29^{o} API	First hole, 15161ft , second 17550 ft

Well	API	Field Name	Target Formation	Company	Date Drilled	Production Results	Comments
2-9H	03043150	Bowerbank	Monterey	Venoco	2011	30-day IP: 11 bopd API 32-37^{o} 80 MCF Cum Prod: <5000 BO	Lateral below 10,000 ft, ~4500 ft deviation. Weak shows. Hydraulic fractured.
TPJ Two #1	03120464	Exploratory NE of Trico	Monterey	Hess	2012	Not produced	TD 9686 ft
Paloma Deep #1	03036090	Paloma	Monterey	Neon	2011	Cum Prod <600 BO, <4000 MCF: API 23^{o} to API 36^{o}	Well plus two sidetracks: TD 10459 ft (3187 m), 11942 ft (3639 m) and 13320 (4059 m).
Scherr Trust et al 1-22	03041006	Semitropic	Monterey	Venoco	2010	<200 BO, no gas reported	TD 14015 ft
Pierce 1-31	03041005	Semitropic, Desert Prospect	Monterey	Venoco	2010	No oil, produced water	
Bullitt 1-7	03042124	Semitropic	Monterey	Venoco	2011	<500 BO Cum Prod. 26.3^{o} API	
BLM 1-29	03039795	Sevier Prospect	Monterey	Venoco	2011	<5000 BO Cum Prod, 30-36^{o} API	
BLM 4-19	03046156	Sevier Prospect	Monterey	Venoco	2012	19,190 BO Cum Prod 33-40^{o} API	Mud log oil shows: 6600 to 7800 ft
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Pierce 1-31	03041005	Semitropic, Desert Prospect	Monterey	Venoco	2010	No oil, produced water	TD 12600
Bullitt 1-7	03042124	Semitropic	Monterey	Venoco	2011	<500 BO Cum Prod. 26.3^{o} API	TD 12750
BLM 1-29	03039795	Sevier Prospect	Monterey	Venoco	2011	<5000 BO Cum Prod, 30-36^{o} API	TD 9600
BLM 4-19	03046156	Sevier Prospect	Monterey	Venoco	2012	19,190 BO Cum Prod 33-40^{o} API	Mud log oil shows: 6600 to 7800 ft
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TPJ Two #1	03120464	Exploratory NE of Trico	Monterey	Hess	2012	Not produced	TD 9686 ft
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BLM 4-19	03046156	Sevier Prospect	Monterey	Venoco	2012	19,190 BO Cum Prod 33-40° API	TD 10500
Thorndyke 882D-8	03047120	Exploratory north of Belridge	Monterey	Aera	2012	8,499 BO Cum Prod 26.3° API	Monterey at 11337 ft, TD 17250 ft. Maximum production rate 150 bopd.
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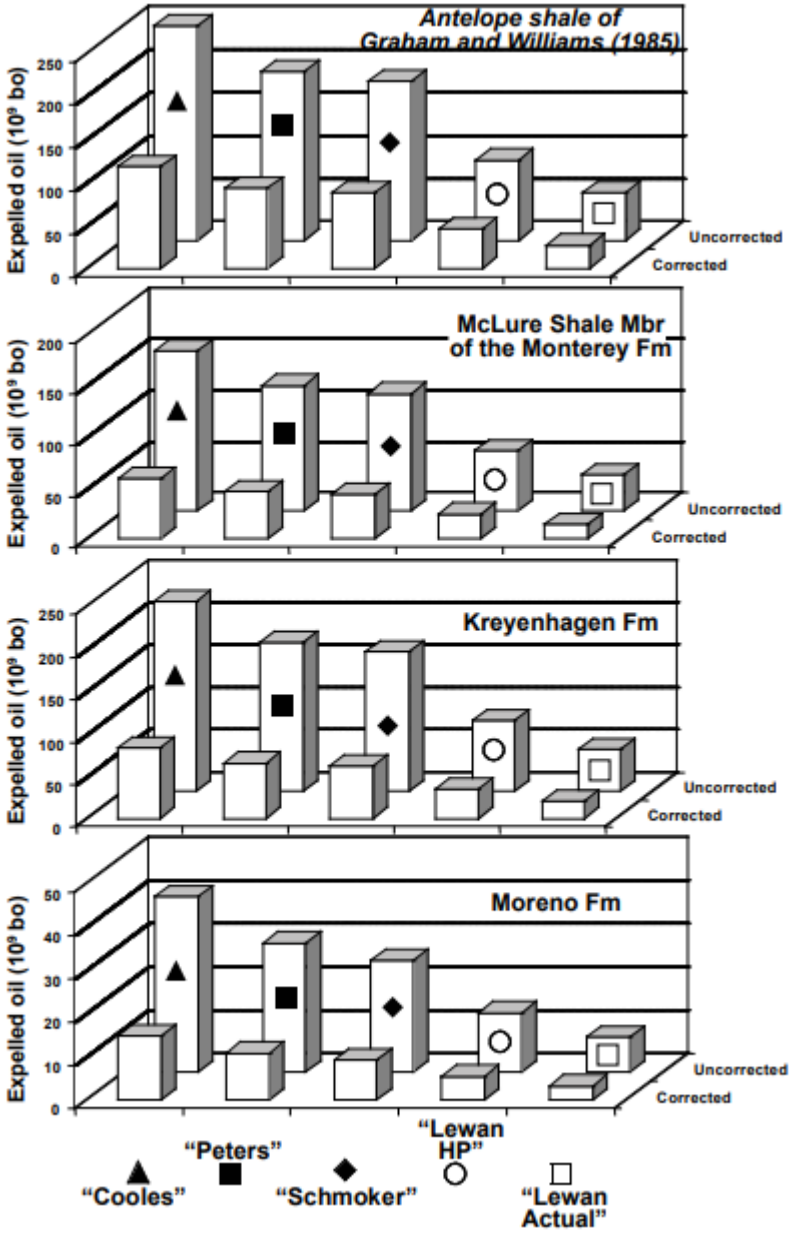
DO THESE TEST THE OIL WINDOW?

Summary and Conclusions

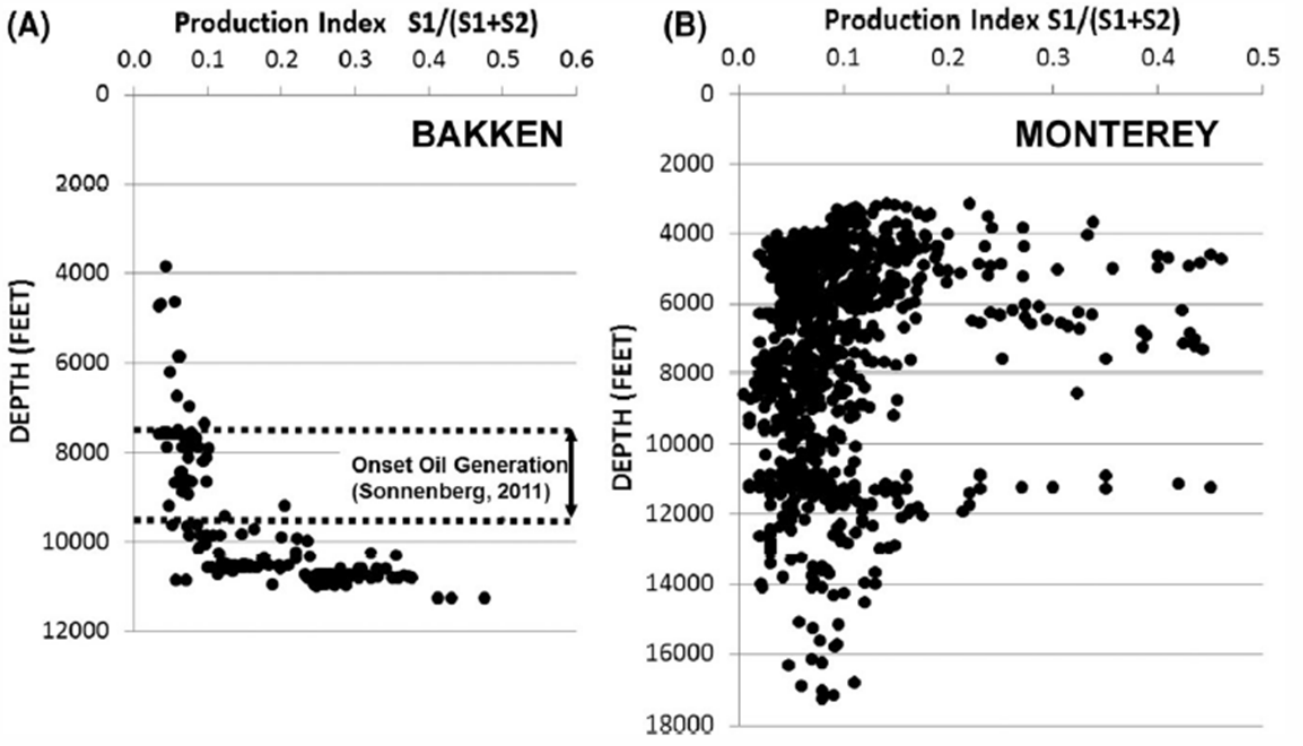
- The three source rocks in the San Joaquin Valley, the Monterey, Kreyenhagen and Moreno, all potentially represent continuous oil accumulations at oil window depths in the subsurface.
- ***Likely there are billions or tens of billions of barrels of oil in these continuous oil accumulations at oil window depths.***
- A more proper moniker for these intervals would be “heterogeneous and discontinuous oil accumulations” in that the distribution of oil saturation is heterogeneous vertically and spatially, and it is therefore difficult to predict optimal areas and depths to target.



Magoon et al 2007

Summary and Conclusions

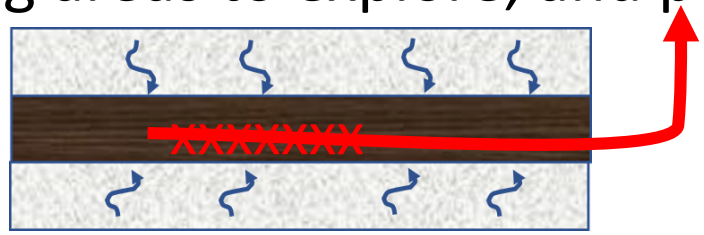
- 1) In general, the quality of the shows for SJV continuous oil accumulations appear *poorer* than the Bakken Formation.
  - Given that the source rock character of the Monterey and Kreyenhagen formation is good to excellent, it is puzzling that at oil window depths the quality of oil shows is more varied and marginal for these intervals than for the Bakken Formation.
  - It is possible that effective drainage between the source rocks and the up-dip reservoirs has left only residual oil saturations in the source rocks at oil window depths.
  - Leakage from the source rocks may be enhanced by fractures in the siliceous shales.



Comparison of behavior of the Rock-Eval production index versus depth for (A) the Bakken Formation (from Price et al., 1984) and (B) the Monterey Formation. Onset of oil generation for the Bakken (from Sonnenberg, 2011) is shown in (A).

Summary and Conclusions

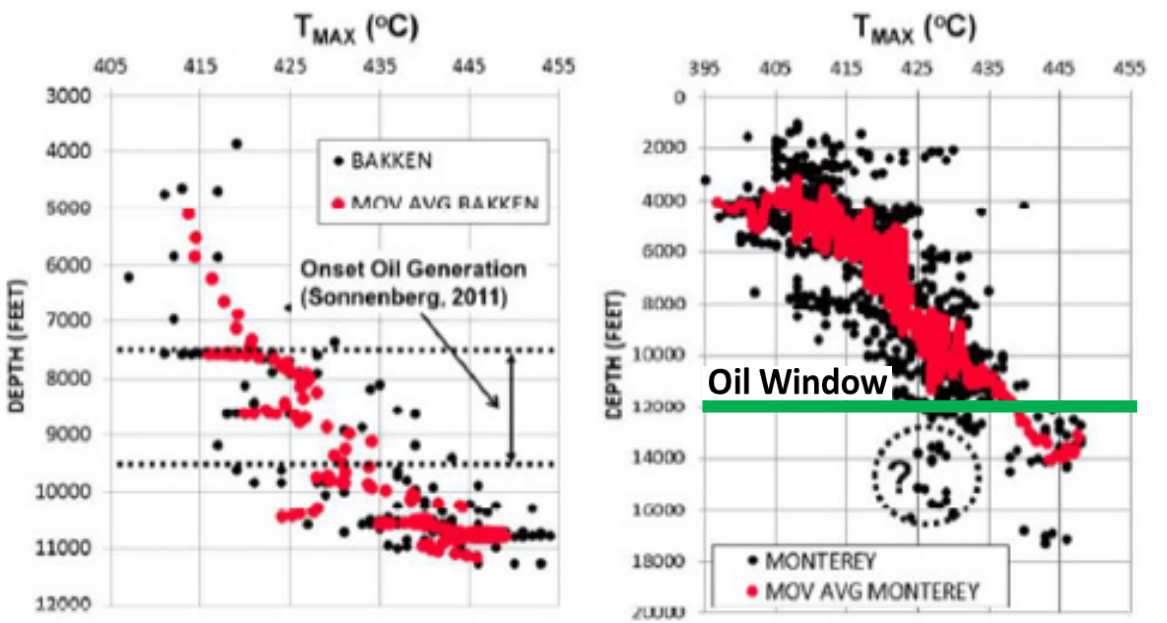
- 2) Complex structural architecture & stratigraphic continuity creates issues of predictability for optimal areas to target.
  - Tectonism, resulting in rapid rates of subsidence over the past few million years, accompanied by thrusting and folding, has resulted in a heterogeneous subsurface pressure regime.
- 3) The lack of a specific hydraulic fracture target, similar to the middle Bakken, further complicates both targeting areas to explore, and potential deliverability.
  - WHERE'S THE "BAKKEN COOKIE"?



- 4) The API gravity of the oils is lower in the Monterey and Kreyenhagen formations than the Bakken Formation.
  - With a lower gravity API, deeper targets with higher GOR are required for optimal production.

Summary and Conclusions

- 5) The oil windows in the San Joaquin Valley are significantly deeper than the Bakken Formation.
  - Deep targets will further impact economics.
- The results of the current study support recent drilling results suggesting that the heterogeneous and discontinuous oil accumulations in the San Joaquin Valley represent troubled resources which are unlikely to become economic without dramatic changes in conceptual models and/or technology.



More detailed mapping of depths to the Oil Window are provided by Magoon et al 2007 and Peters et al 2007, and are in broad agreement with the above

Billion Dollar Questions….

- What depth is needed for an optimal fraccable target?
- What is the optimal spatial location for a fraccable target?
- What is the best lithology for fraccing?
- How do we recognize a completion target?
- Is structural closure required or even optimal?
- Are there benefits for considering Moreno vs Kreyenhagen vs Monterey as targets? Is the Monterey really the best target?
- Can economic flow rates and cumulative production be achieved at these depths in the San Joaquin Valley, if so, using what production types?

Geologic Research Directions: Refining the "Bakken Analogue Play" in the SJV

The Bakken Analogue for the SJV has been tested at a PRELIMINARY LEVEL, as described previously

For the NEXT PHASE of investigation: what's missing?

- **Creation of a "Working Model" for the Deep Resource play of the SJV, with focus on defining what's missing**
- **Detailed reservoir characterizations are needed** for regions sampled by deep wells with ample data
- **Characterization of subsurface pressures and evolution of pressures**
- **Characterization of stratigraphic heterogeneity** with implications for predictability of oil saturation and locating prime fracc targets

- What is the **total volume of oil in the Oil and Gas Window (OOIP)**, with uncertainty?
- What are the **distributions of oil saturation in the Oil Window and Gas Window**?
- What are the **geomechanical properties of likely fraccable units at Oil and Gas Window depths?**
- What are the **oil saturations in likely fraccable units?**
- Does **API gravity change with depth** or spatially in the source rocks?
- **Further refinement of the foundational work** by Peters et al (2007) and Magoon et al (2007) to specifically address "deep resource" potential
- Creation of a **deep resource database**