

Exploration and EOR potential of the Tensleep Formation, S.E. Wyoming Using the Play-Based Method

S.G. Fryberger *1, N. Jones*2, M. B. Johnson *2

*1 Fryberger Petroleum; Laramie, Wyoming; *2 Enhanced Oil Recovery Institute, University of Wyoming, Laramie, Wyoming
Prepared for Rocky Mountain Association of Geologists, Denver, December 2016



The Permian Upper Tensleep Formation at Flat Top Anticline near Medicine Bow, Wyoming

Acknowledgements

Our work in Southeast Wyoming was made possible by many kind landowners and mineral owners in the region. We owe thanks to Deb Bailey and the folks at Two Rivers Ranch and Joan McGraw of Medicine Bow Conservation District for access to the important Flat Top Anticline. We also thank Steve Bartlett and Brian Tideman at the Pete Lien and Sons Quarry near Livermore, Colorado for access to important outcrops in the Lyons and Ingleside Formations (correlatives of the Tensleep) on their property. Brenda and the folks at Lyons Sandstone Quarry in Lyons, Colorado allowed access to definitive outcrops at their quarry. Thanks to Chimney Rock Ranch at Sand Creek for access to the classic Tensleep/Casper outcrops near the ranch and for their support of the University of Wyoming research for many years. We thank Shelly for access to the privately held Paradise Valley section in the Upper Tensleep/Casper Formation near Laramie.

Thanks also to the Wyoming Geological Association for use of figures from various WGA publications cited in this talk (some of which go back many years!). Also, copious thanks to Shell Oil for use of non-proprietary Play Based exploration concepts from the Guide for AAPG's Imperial Barrel Award Participants. We thank Josh and Terry at the USGS Core Research Center in Lakewood, Colorado for excellent layout of core from Wertz and Quealy Dome oil fields which was very helpful to our study. We also thank Google for Google Earth views that were very helpful in recording the routes of our measured sections.



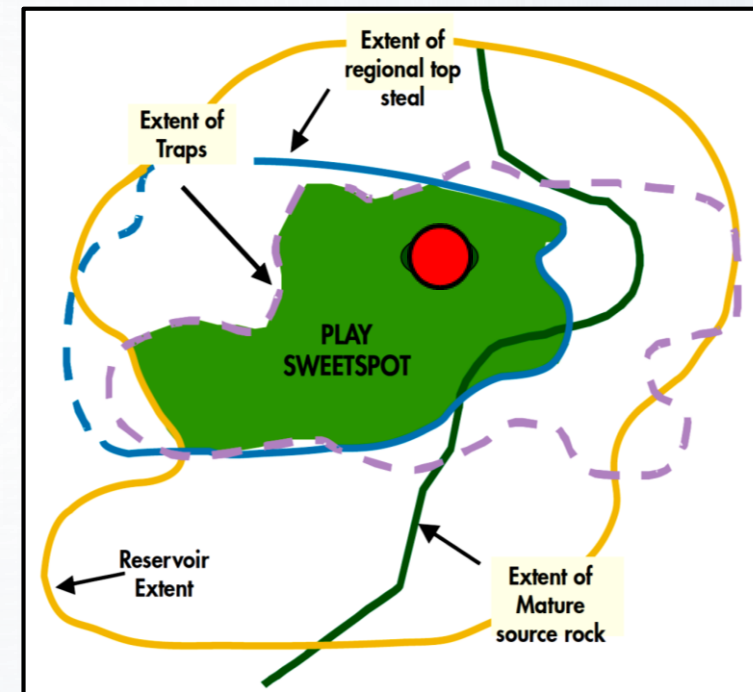
Upper Tensleep/Casper Formation stacked dunes at Sand Creek near Laramie.



Old oil: sign just off US Hwy 287, showing the way to Oil Springs production. Near the oil-saturated Tensleep sandstone at Flat Top Anticline

Play-Based Common Risk Segment Mapping:

Common Risk Segments (CRS) are geological risk elements for petroleum exploration or development (commonly **reservoir, source and trap**) that have a definable, quantifiable and geographically mappable distribution. The assessments of CRS segments are the product of judgment by an experienced geologist of the relative risk embodied in terms such as “low risk of no charge” versus “high risk of no charge” for example. These evaluations are based on understanding the geology of a region. CRS evaluations can also be expressed as possibilities for success (POS) as percentages from zero to 100, or statistical categories such as P5-P50-P95 for probabilistic estimates. In this report we evaluate risk in terms of a common set of geological risk factors perceived to be typical of a region (such as the Atlantic Rim).

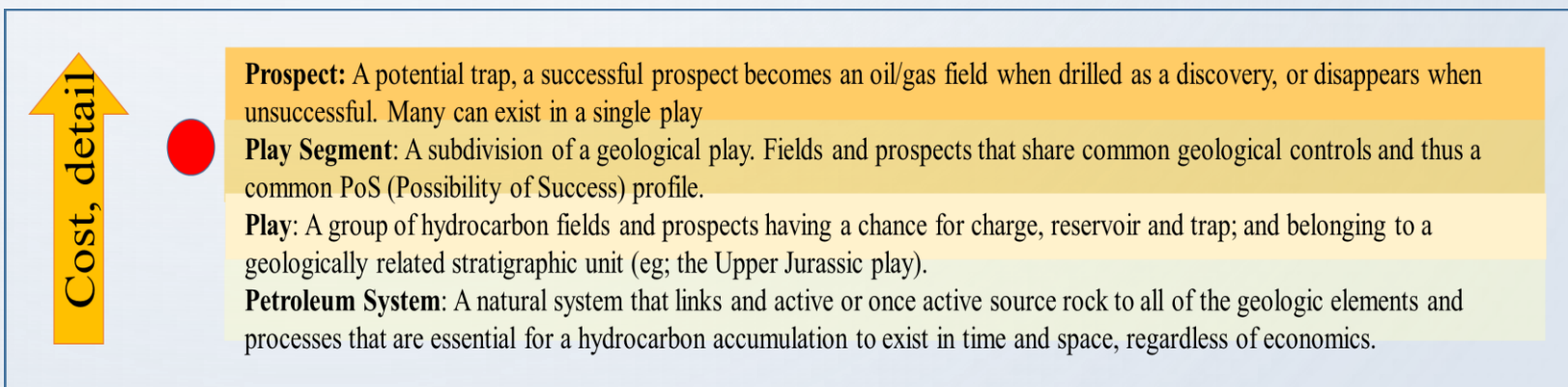
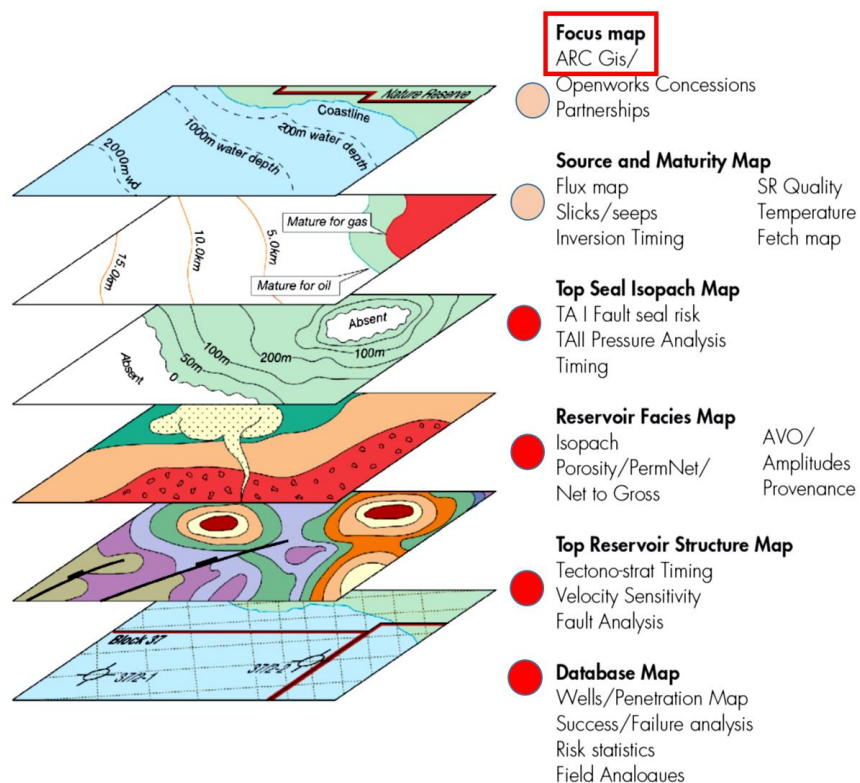


(Left) **The logic of geological risking involves the stacking of geological risk elements. A play exists where risked geological factors fulfill the requirements for the existence of an oil field** or a productive region of a basin. The overlap area in which all factors are positive, or “low risk” identifies a natural sweet spot.

● Focus of this talk

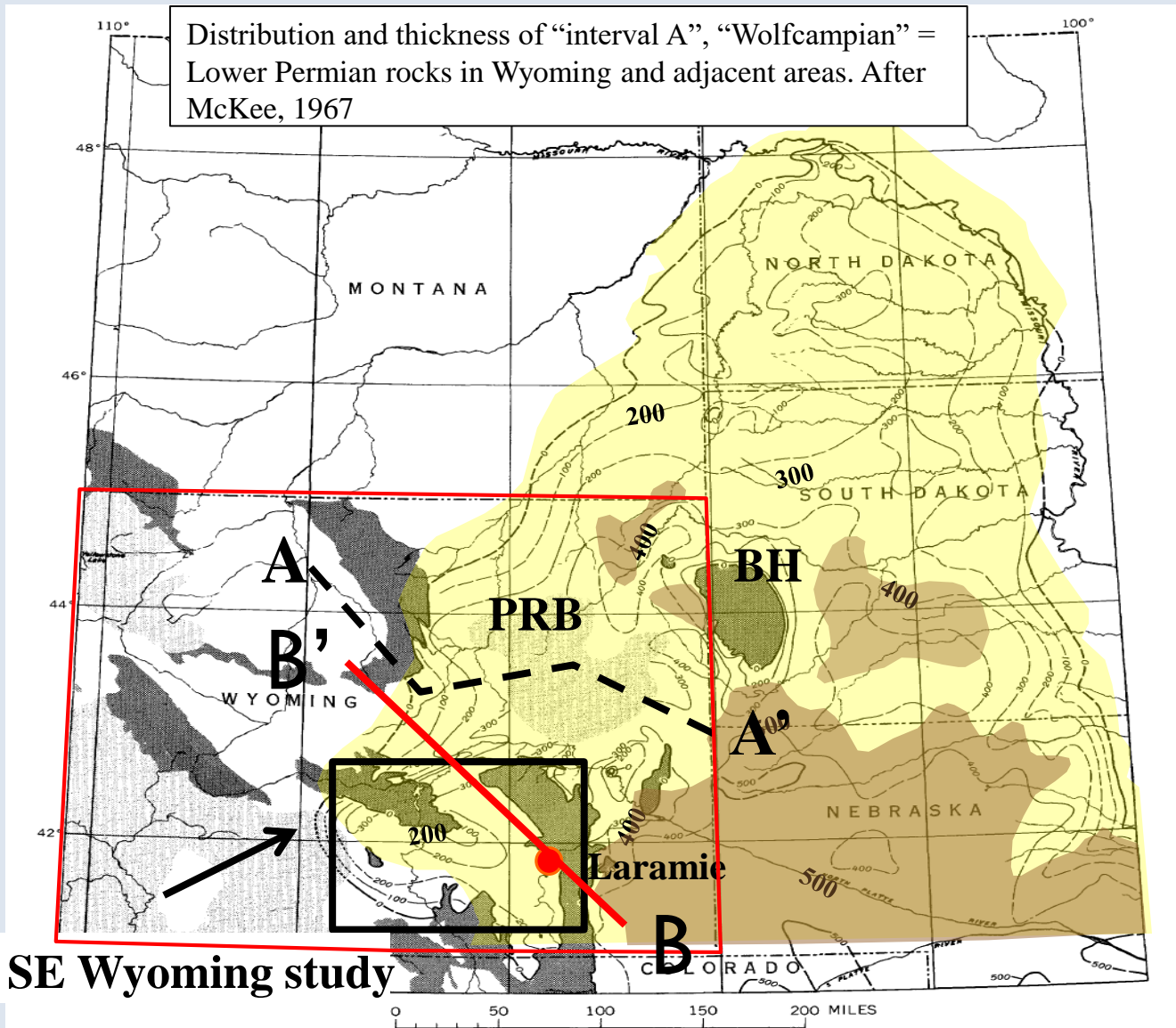
(Left) The method we used to take a fresh look at the Wyoming Tensleep and Minnelusa petroleum systems and CRS high-graded exploration and production opportunities. We have picked proprietary databases of tops and geology, and **stacked the key maps** as indicated by the red dots. We have not explicitly evaluated source rock maturity, instead using indicators of charge such as oil shows and production that confirm oil migration into a region. We have not evaluated land and partnership frameworks except very generally such as “this is the UP railroad strip, etc.” as these considerations apply more at prospect level.

Data structure overview



Concepts and illustrations on this page after Shell Exploration and Production, (2006) Play Based Exploration: A Guide for AAPG’s Imperial Barrel Award Participants; and De Jager, J., and Stephen Wright, 2006

Lower Permian (Wolfcampian) isopachs in Wyoming



SE Wyoming study

FIGURE 46.—Thickness of interval A in central Wyoming, eastern Montana, the Dakotas and parts of adjacent States discussed in this chapter. Isopach intervals 100 and 500 feet. Isopachs dashed where control is poor, dotted where Permian rocks have not been penetrated by drill. Dark pattern, areas where rocks older than Permian are exposed; light pattern, areas where rocks younger than interval A have not been penetrated.

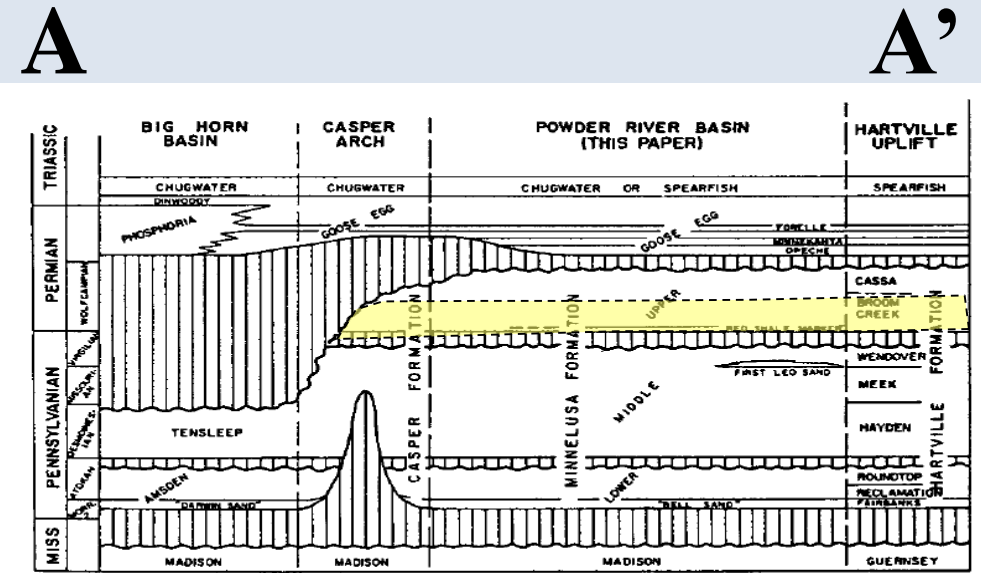


FIG 1 DIAGRAMMATIC CORRELATION OF PERMIAN-PENNSYLVANIAN ROCKS OF CENTRAL & EASTERN WYOMING

Regional unconformities in the Permo-Pennsylvanian rocks of Wyoming. After Foster, 1958

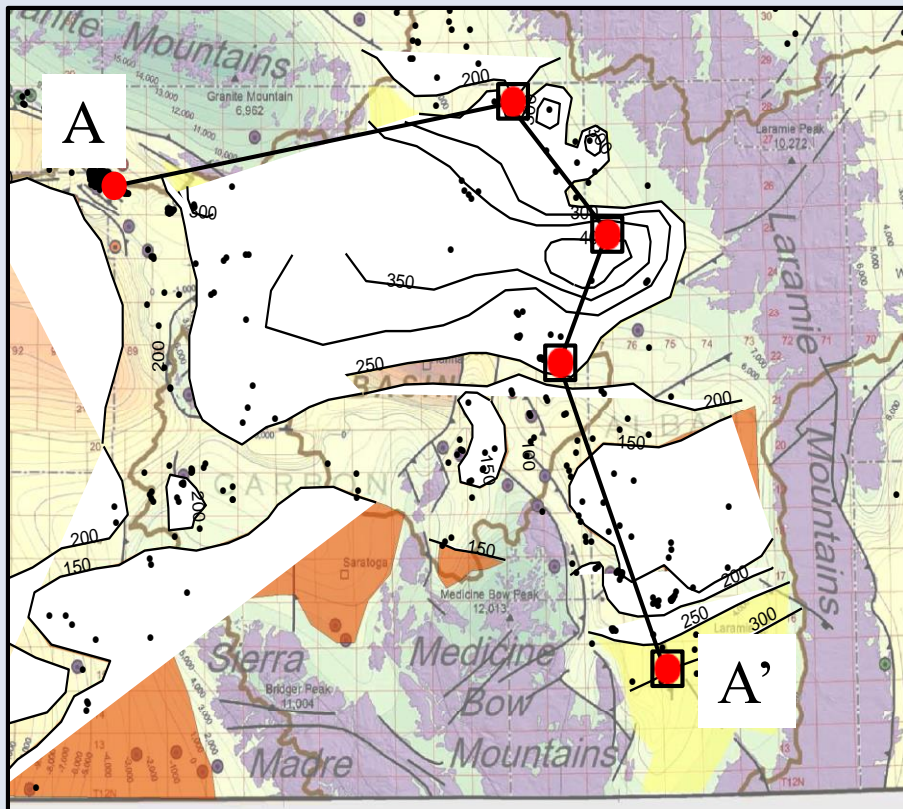
- Interval A of Paleotectonic maps
- Interval B of Paleotectonic maps

TABLE 2.—Subdivisions of the Hartville Formation proposed by Condra, Reed, and Scherer (1940) and their approximate ages (Love and others, 1953; Agatston, 1954; Foster, D. I., 1958)

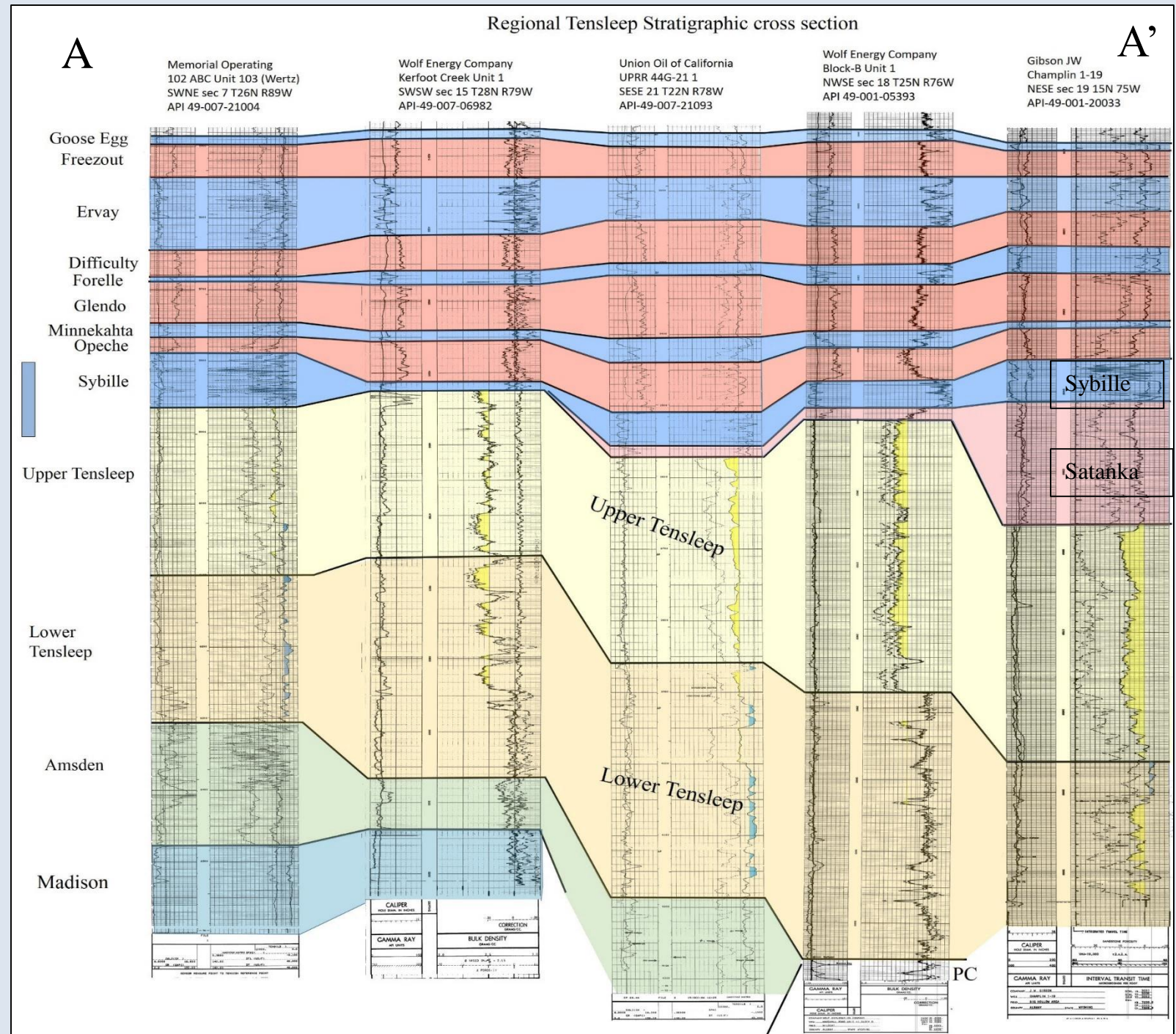
Division	Group	Approximate age	System
I	Cassa	Leonard	Permian
	Broom Creek	Wolfcamp	
II	Wendover Meek	Virgil Missouri	Pennsylvanian
III	Hayden	Des Moines	
IV	Round Top		
V	Reclamation	Atoka	
VI	Fairbank	Morrow(?)	

Subdivisions of the Hartville Formation, SE Wyoming. After McKee et al, 1967

Tensleep Stratigraphy Southeast Wyoming



Route of the cross section at right (red squares). Index map shows upper Tensleep thickness, Yellow shaded areas have Upper Tensleep thicker than 200 feet; Orange areas are thinner than 150 feet. Background is Wyoming basement map.



Cross section of the Tensleep Formation in Southeast Wyoming. Section is hung (loosely) on the top of the Ervay Member of the Goose Egg Formation

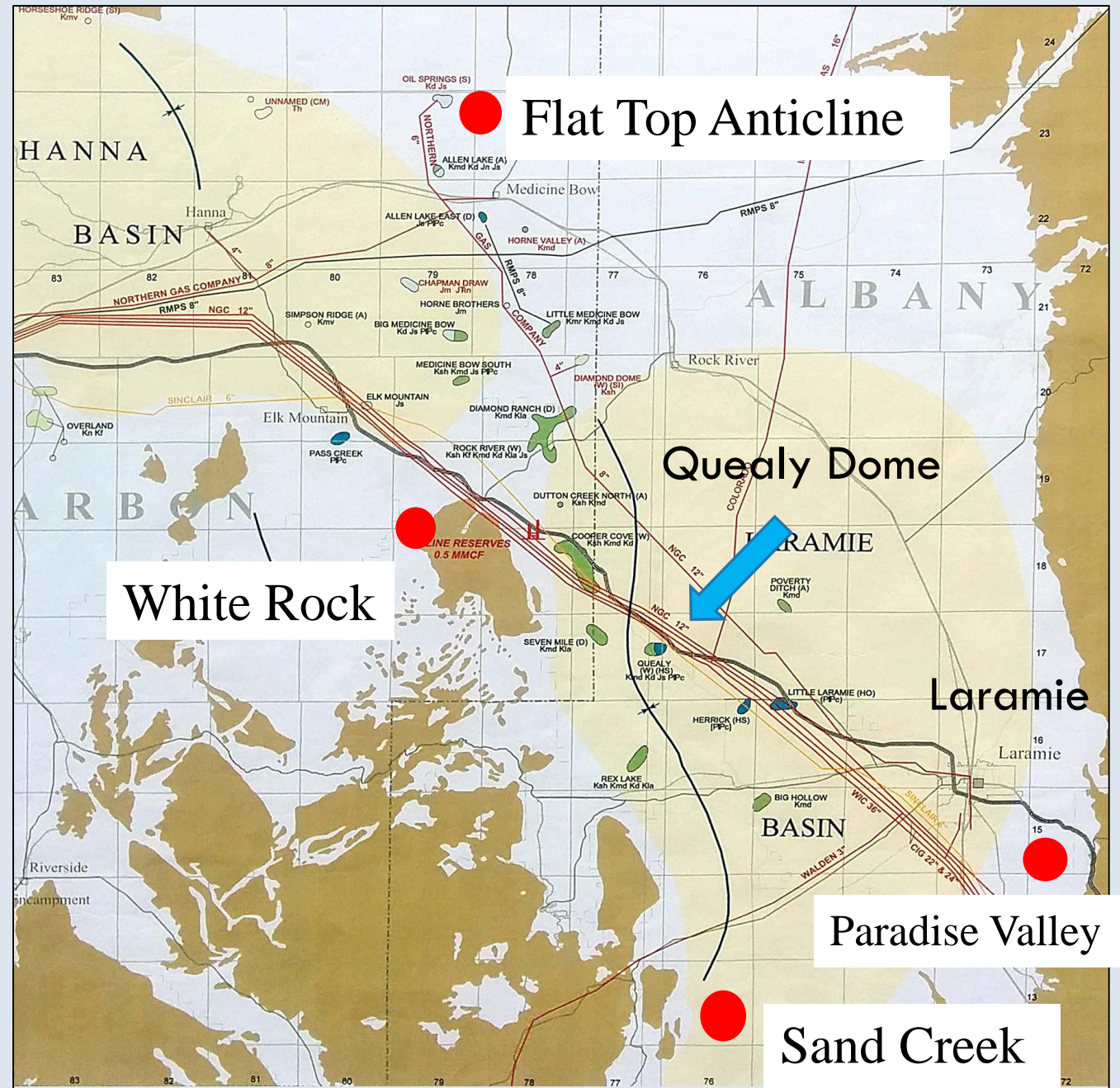
Tensleep outcrop studies in the Laramie and Hanna Basins



Nick Jones measuring the Upper Tensleep section at White Rock Canyon



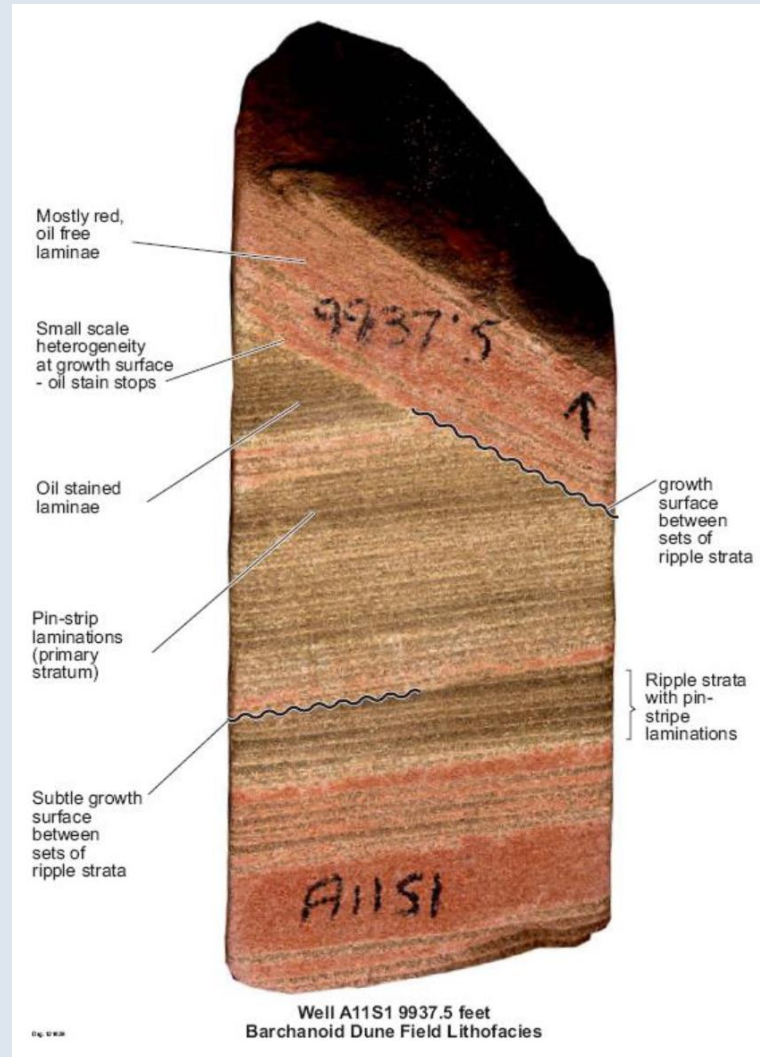
Oil-saturated eolian avalanche primary strata, Upper Tensleep, Flat Top Anticline



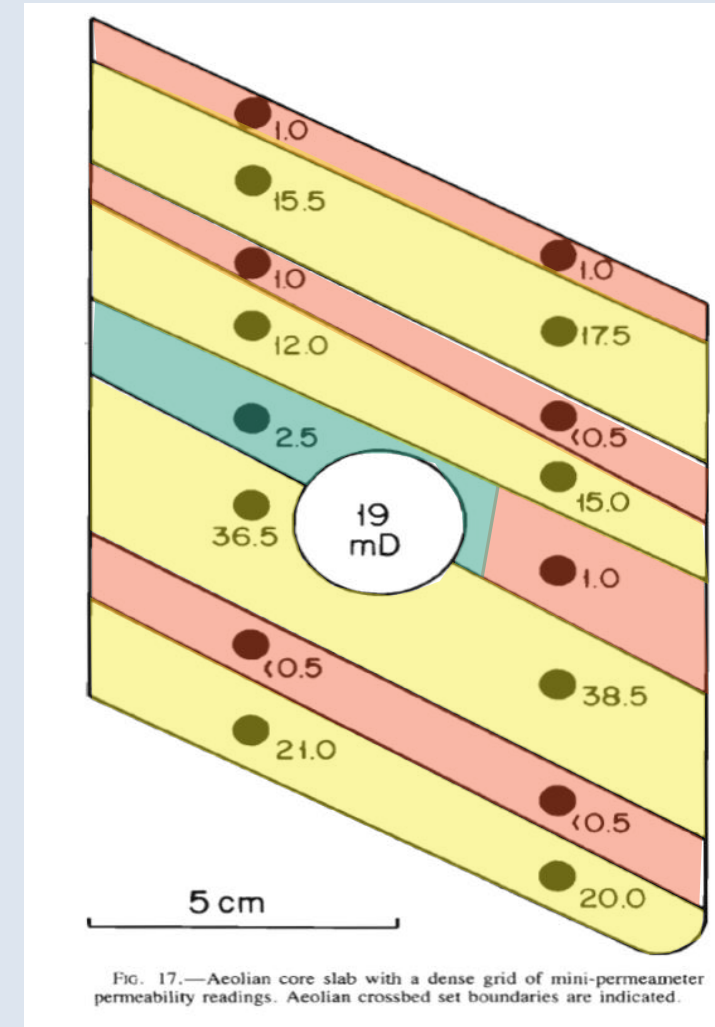
Above right: Oil Fields with production from Pennsylvanian-Permian rocks are shown in dark blue. Cretaceous production (commonly Muddy SS) is shown in dark green. Measured sections are shown as red dots.

Eolian Permeability variations at laminar (primary strata) scale

Most of the critical flow effects of eolian cross bedding and cross strata are due to strong differences in porosity and permeability between individual laminations, as illustrated in the two figures here. The isolation of permeable laminae by tight laminae will drastically reduce sweep efficiency in rocks that, on standard logs and core plugs, appear quite permeable. These microfabrics also create anisotropic sweep tendencies in the rocks.



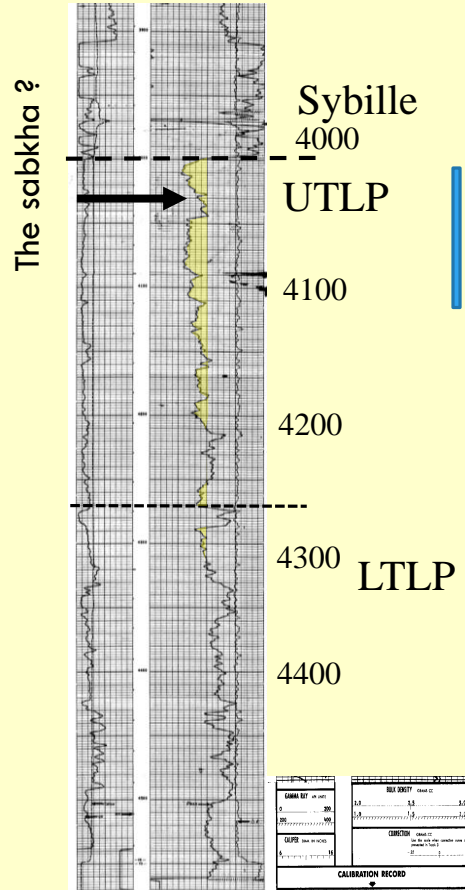
Core from eolian strata in Auk Field, Permian Rotliegend sandstone, UK. North Sea. Brown laminae are oil stained, red and white laminae have no oil. After Trewin, Fryberger and Kreutz, 2003



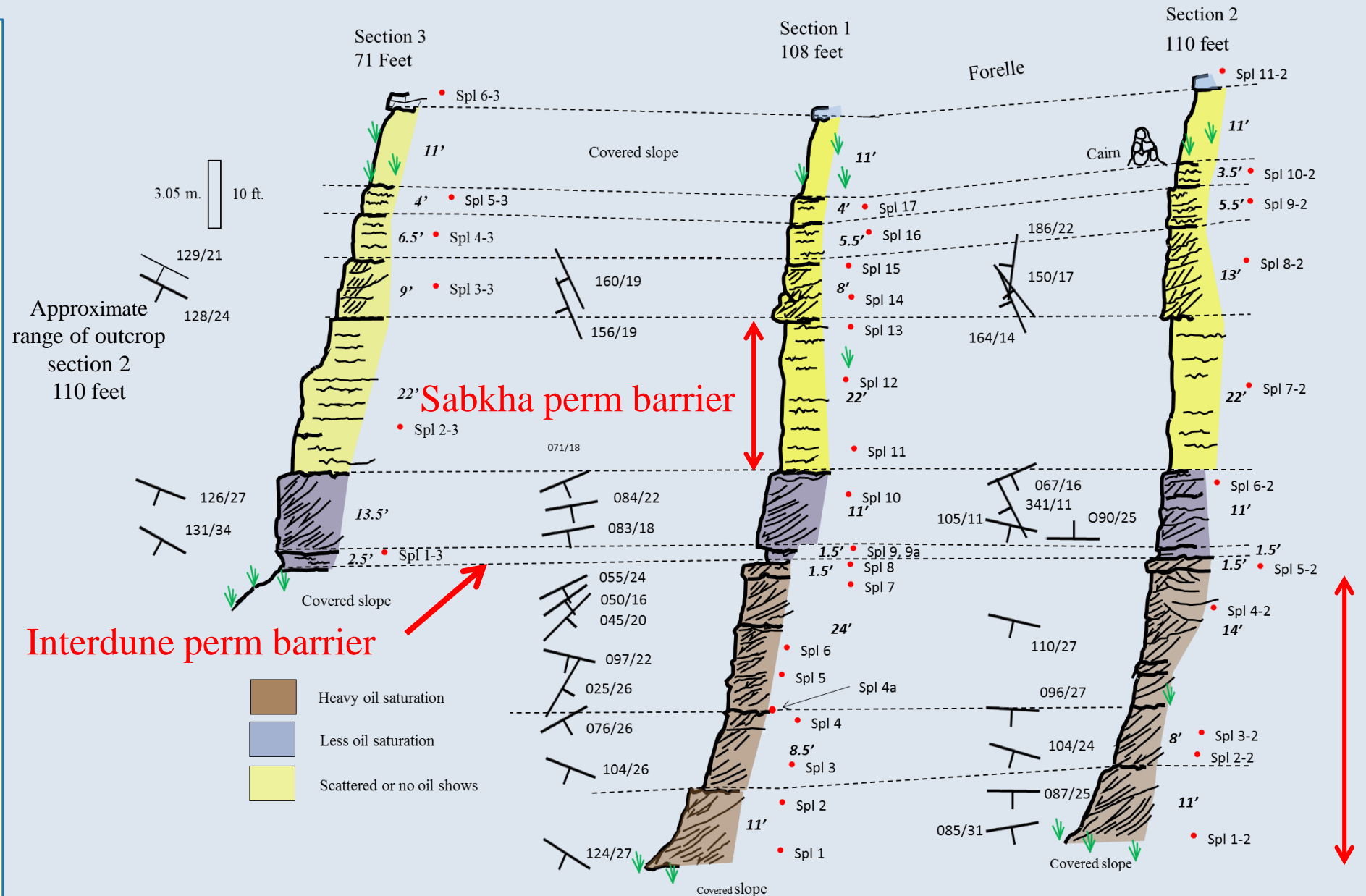
Laminar –scale variability of permeability, measured with a minipermeameter. After Weber, 1987

Upper Tensleep Formation: Flat Top Anticline, Carbon County north of Medicine Bow, WY

49-007-20631
 QUINTANA PETROLEUM CORP
 FEDERAL 1 ALLEN LAKE EAST
 2096 FSL AND 1914 FEL (NW SE) 18
 22 NORTH 78 WEST
 41.877033 -106.215845



Density-GR log of the Federal 1 Allen Lake East oil well that penetrates both the Upper and Lower Tensleep at nearby Allen Lake East (Tensleep) oil field. The sabkha encountered at Flat Top Anticline may be present in this well (arrow).



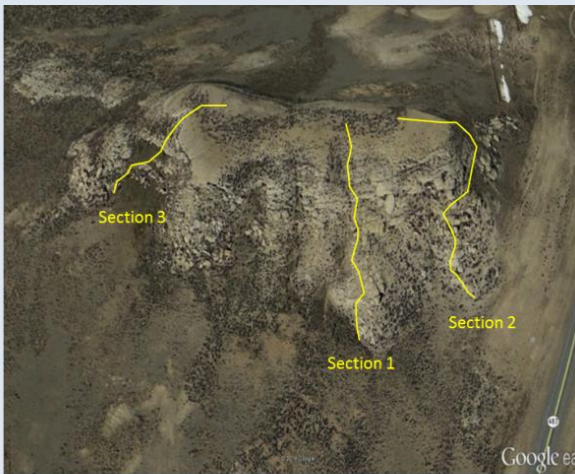
Upper Tensleep at Flat Top Anticline, Medicine Bow, WY

Reservoir flow units: Stacked facies, bedforms and primary strata

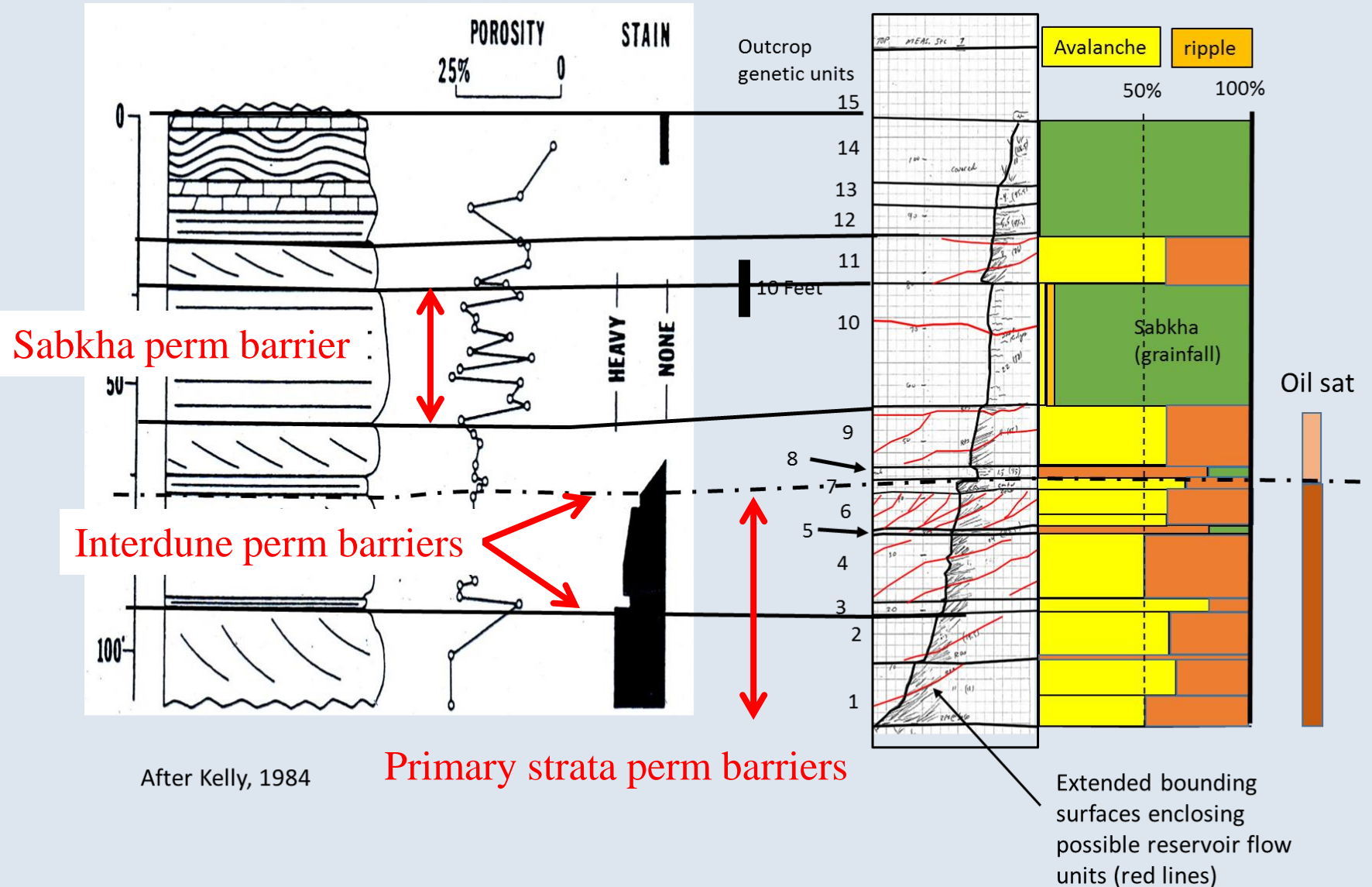
Correlation of Kelly, 1984 Porosity data with EORI Measured section 1



Eolian slipface deposits consisting of a mixture of avalanche and ripple strata, Unit 1, measured section 1. These sandstones are saturated with heavy, live oil. View is to the west, cross beds dip south, indicating wind from the north.



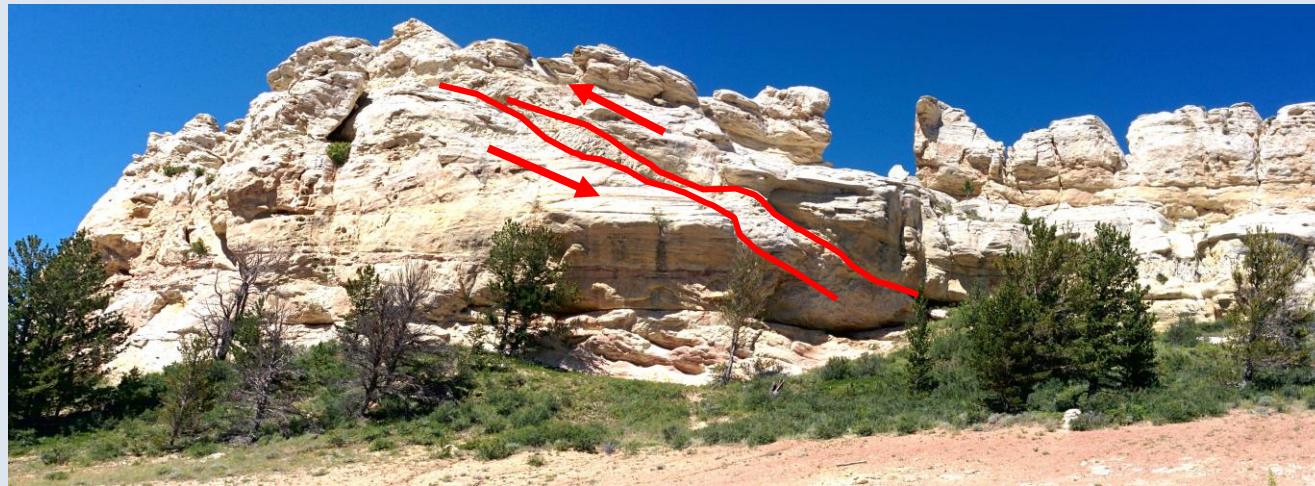
Light-colored exposures of the Upper Tensleep Formation in the core of the flat top anticline. Routes of measured sections are shown by yellow lines.



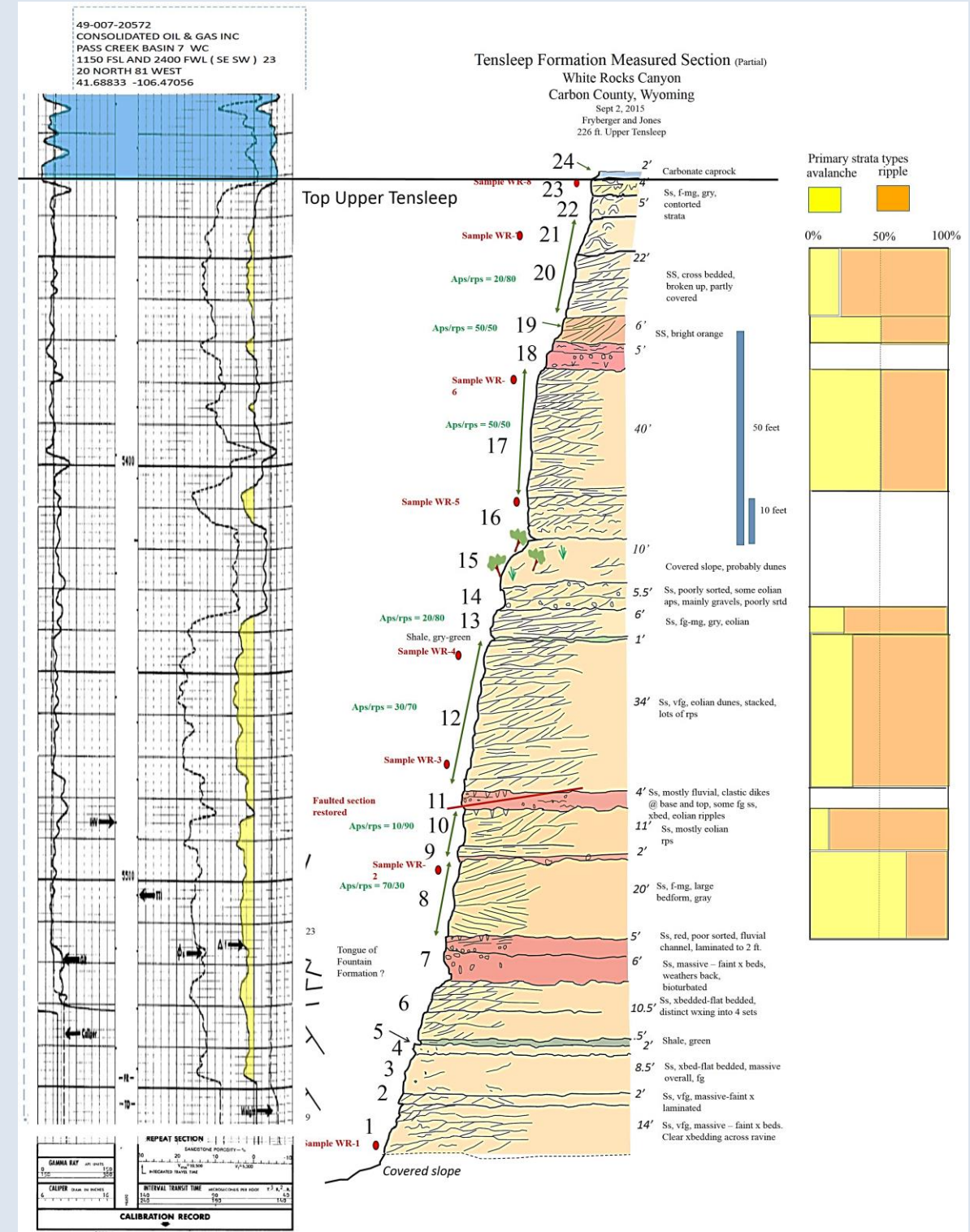
White Rock Canyon, WY, Upper Tensleep



Eolian avalanche and ripple primary strata in unit 17. Close study of the image reveals that 80% of the outcrop is ripple strata, despite the relatively steep dips.

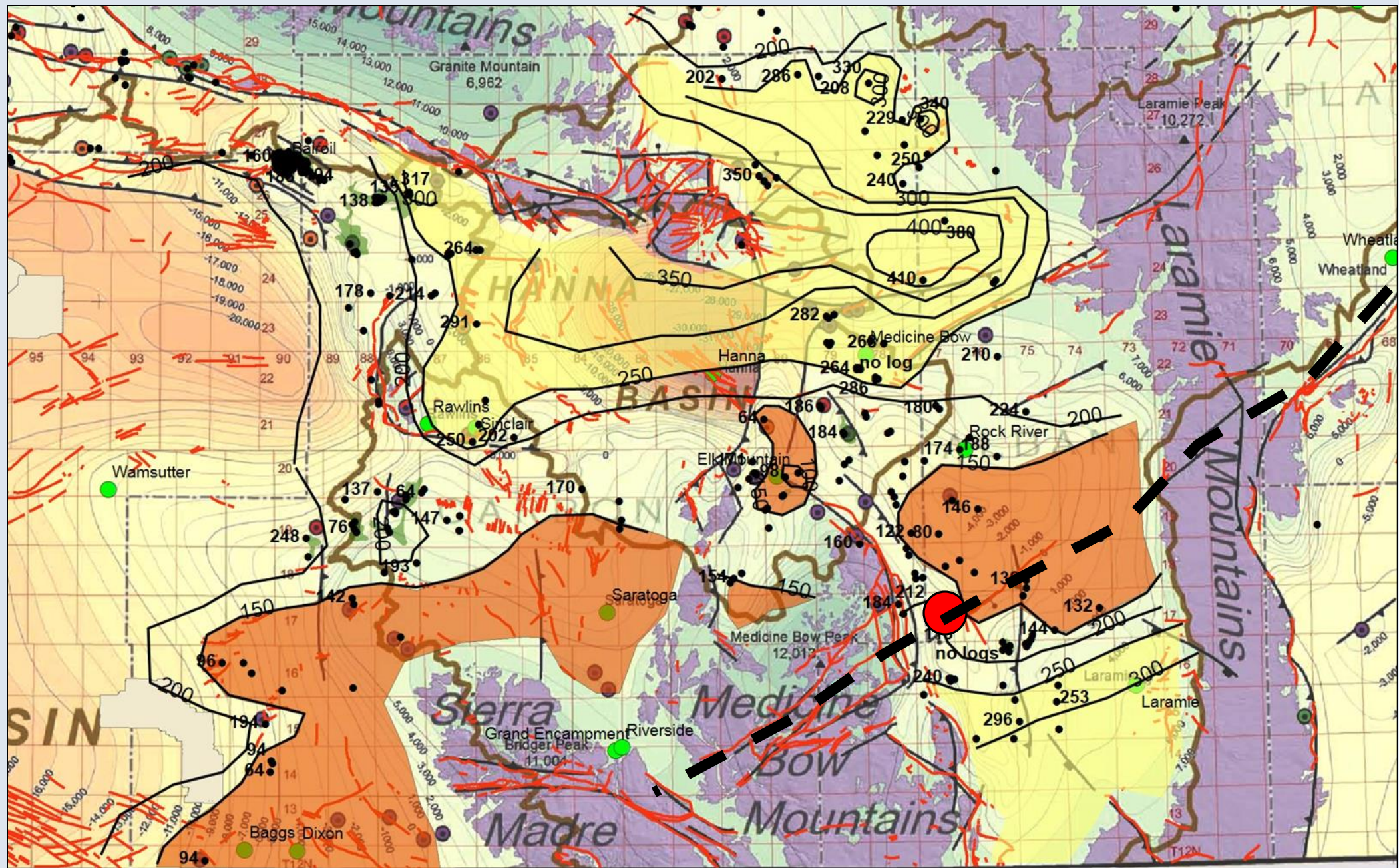


The Upper Tensleep Sandstone at White Rock Canyon, east side of outcrop. Our 226 foot (partial) measured section began in the Upper Tensleep, which in this area is roughly 400 feet thick, based on well control. It was measured on the opposite (west) side of this cliff where access was easier. It begins about the middle of the Upper Tensleep and continues to the first carbonate in the Phosphoria (Goose Egg) Formation. See log this page for comparison. Note the variety of genetic units in terms of thickness, shape and crossbedding. This suggests that oil recovery factors from these genetic units would be equally diverse, mainly as a function of the arrangement of primary strata in each, as well as geometry, lithology, cross-flow between genetic units etc.. Thrust fault zone of deformation shown by red heavy red lines on image above, and photograph.



Upper Tensleep thickness Southeast Wyoming

Tensleep thicker than 250 feet is shown in yellow, thinner than 150 feet is shown in orange. Thick Upper Tensleep is associated with the Hanna Basin, Northern Laramie Basin and SE Laramie Basin. Thin in the Laramie Basin straddles the Cheyenne (Deformation) Belt, shown by heavy dashed line.



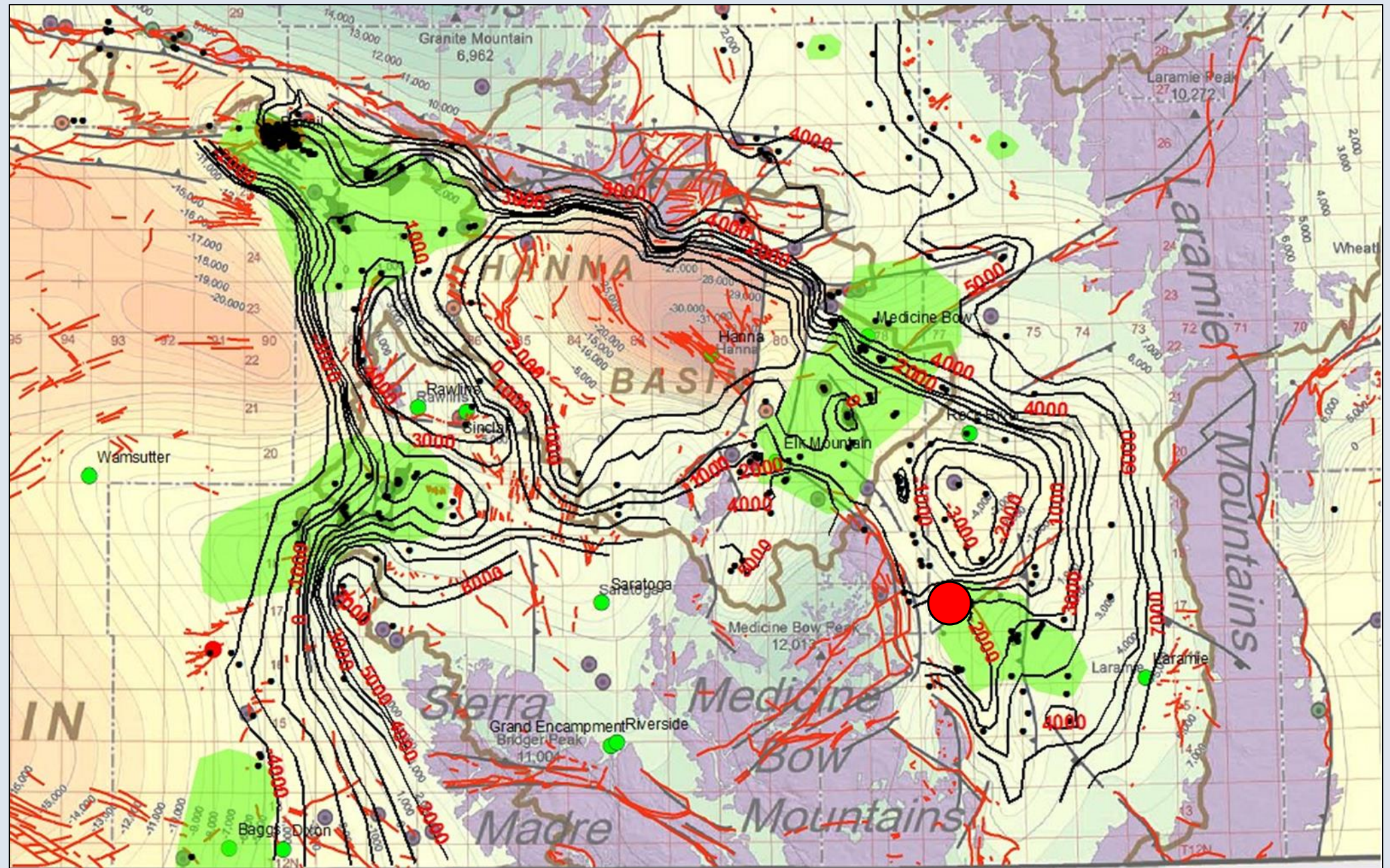
Faults



 Quealy Dome Oil Field

Oil shows in Upper Tensleep Southeast Wyoming

Green areas on this map enclose regions with oil or gas shows in the Upper Tensleep, based on Wyoming Oil and Gas Commission records of production, drill stem tests and some limited core and sample data. This map also shows **major faults in red** from the state geological map, and **structure contours subsea on the top of the Upper Tensleep**. There are distinct, structurally-defined shows in Wertz, Atlantic Rim, Baggs, Medicine Bow and Quealy Dome regions.

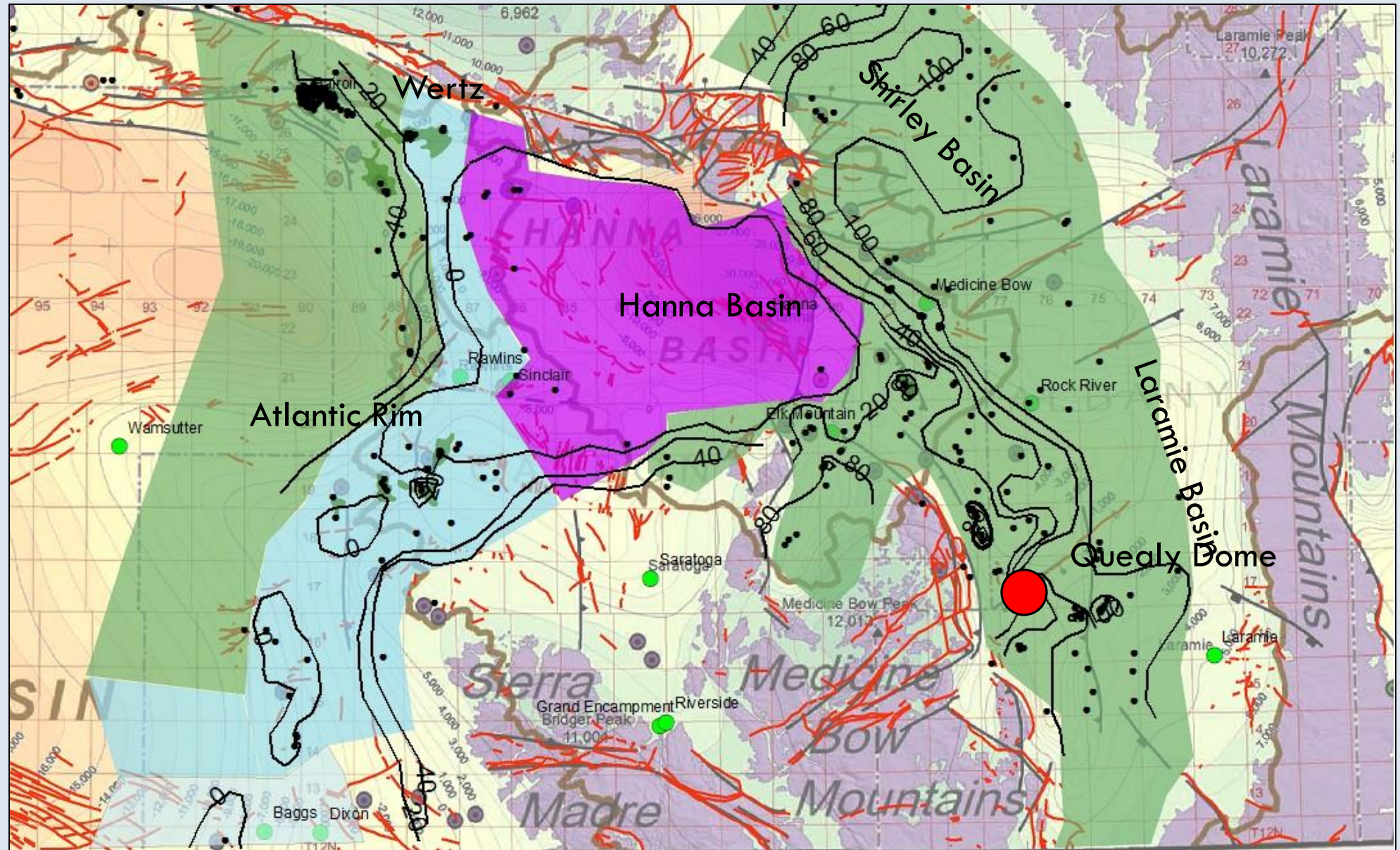


● Quealy Dome Oil Field

Upper Tensleep Reservoir risk (quality) Southeast Wyoming

Tensleep reservoir common risk segment (CRS) map (quality) based on porosity and permeability of Upper Tensleep sandstones.

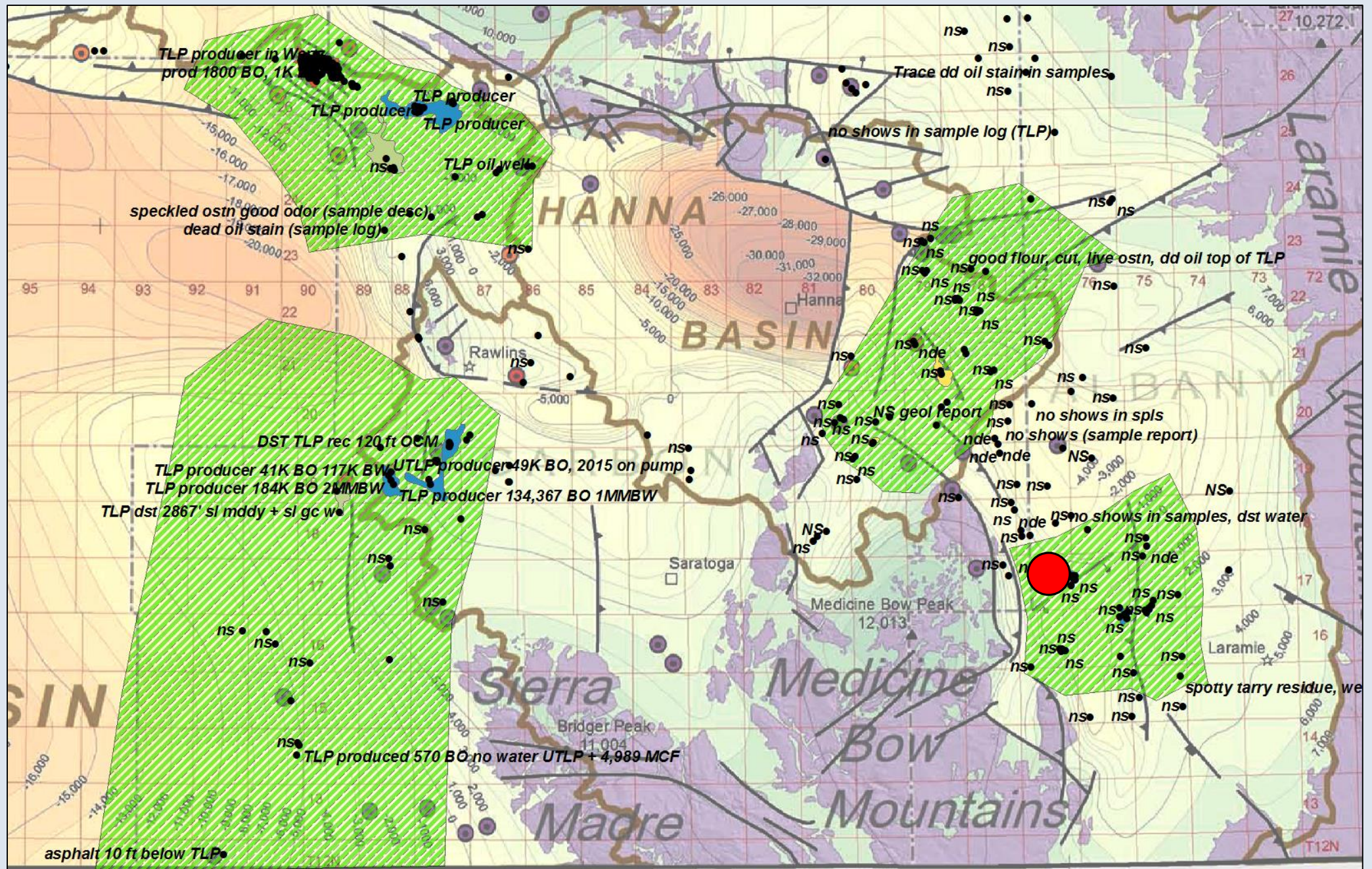
Contours show net/gross in Upper Tensleep, with net cutoff at 65 ms/ft (10% porosity), thus this is a conservative map. The map does not consider fracture-dependent production or exploration opportunities. Green, Low risk; Blue moderate risk; purple, high risk. Regional faults shown as red lines, State of Wyoming basement map as background.



● Quealy Dome Oil Field

Upper Tensleep Charge Risk Southeast Wyoming

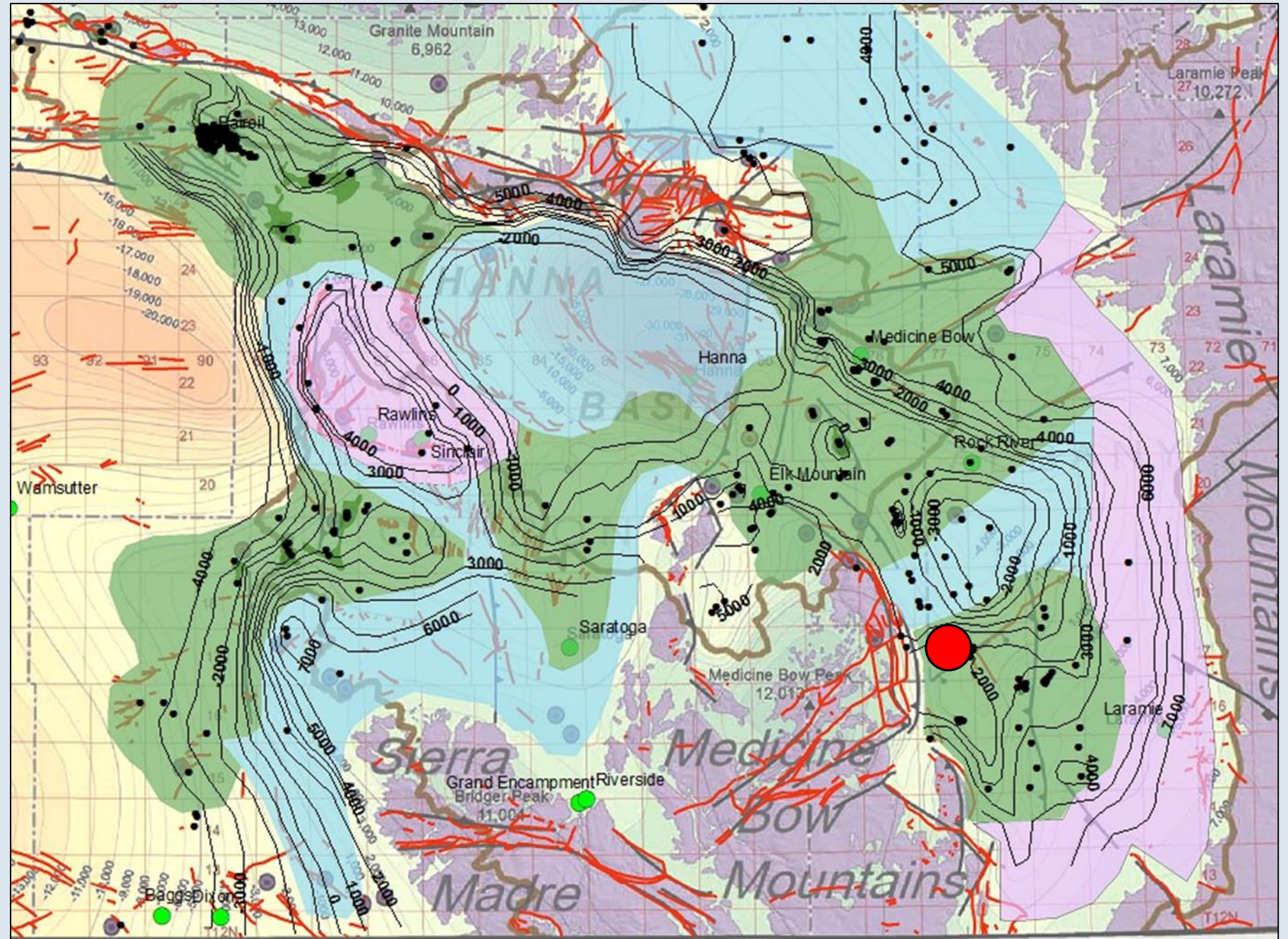
Areas of best shows are shown by green polygons that enclose producing oil fields and oil shows from state records (posted on map). Areas of lower risk are drawn to extend along structural or stratigraphic trends.



● Quealy Dome Oil Field

Tensleep trap (structural) risk map Southeast Wyoming

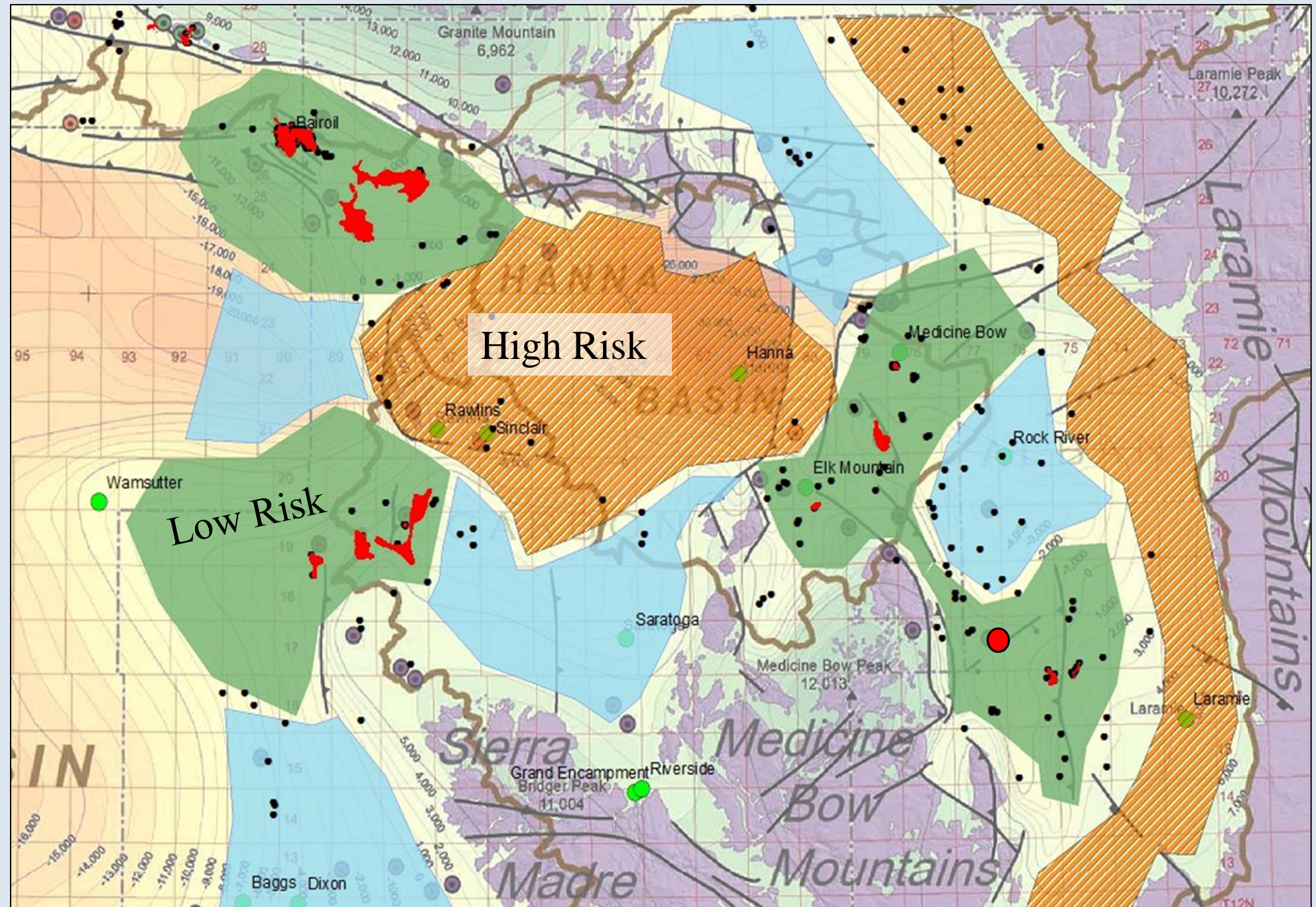
Contours show subsea top Upper Tensleep. Green shading is low risk; blue shading is moderate risk; purple shading is high risk. Regional faults shown by red lines, background is Wyoming Basement map. This map is based on distribution of known producing structures at Tensleep level, and structural setting. In Southeast Wyoming, there do not appear to be stratigraphic traps above intra-formational (reservoir heterogeneity) level in the Upper Tensleep in this region.



● Quealy Dome Oil Field 17

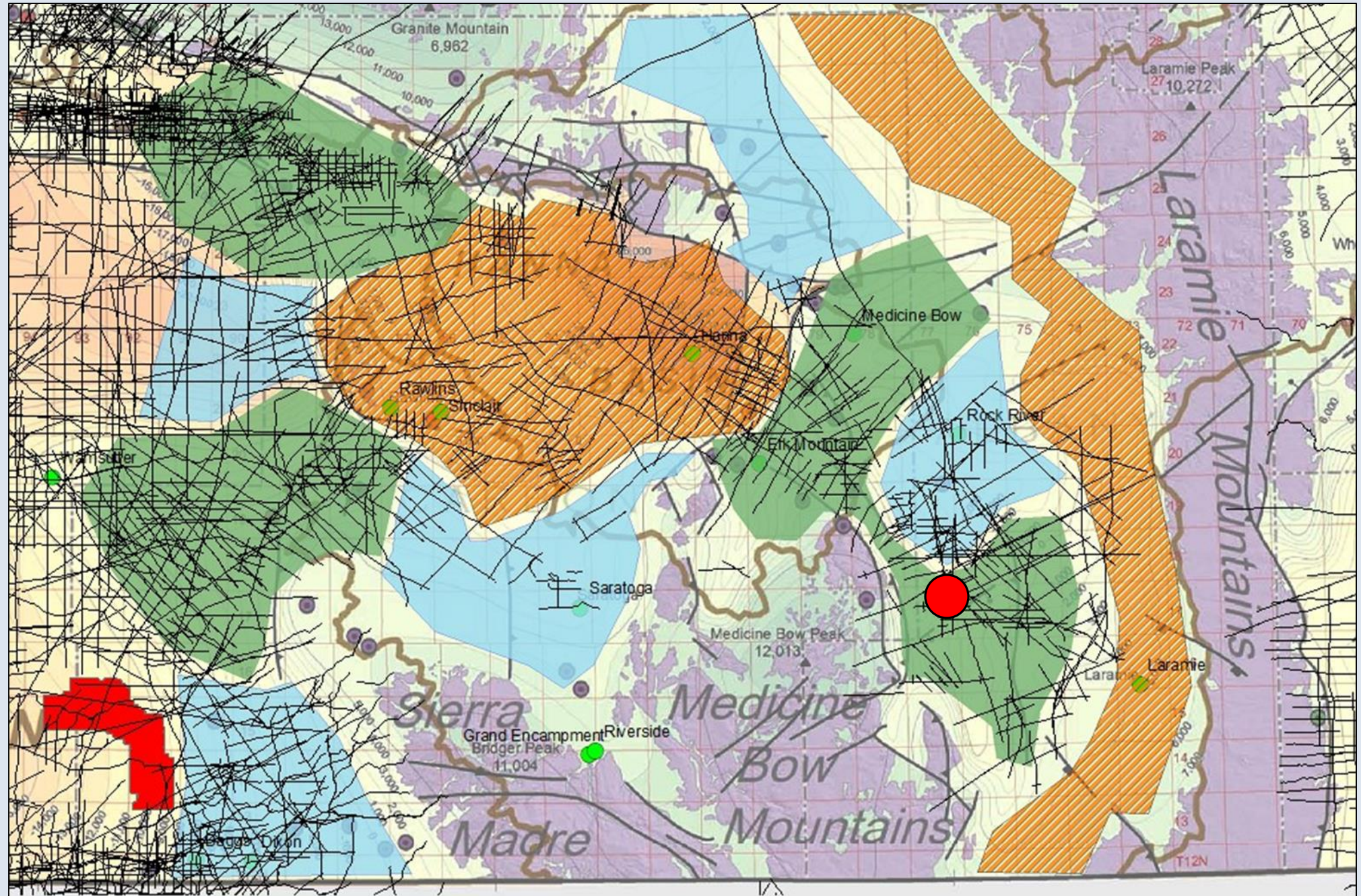
Upper Tensleep Common Risk Segment map Southeast Wyoming

Green areas show regions of best chance to find new production (lowest risk). Blue areas show moderate risk. Orange hachured areas show high risk areas, mainly regions such as the Hanna Basin with tight rock, or areas with insufficient evidence for robust structural traps such as the west side of the Laramie Mountains. State of Wyoming basement map as background. Red outlines show Tensleep oil fields.



Availability of trade seismic data Southeast Wyoming

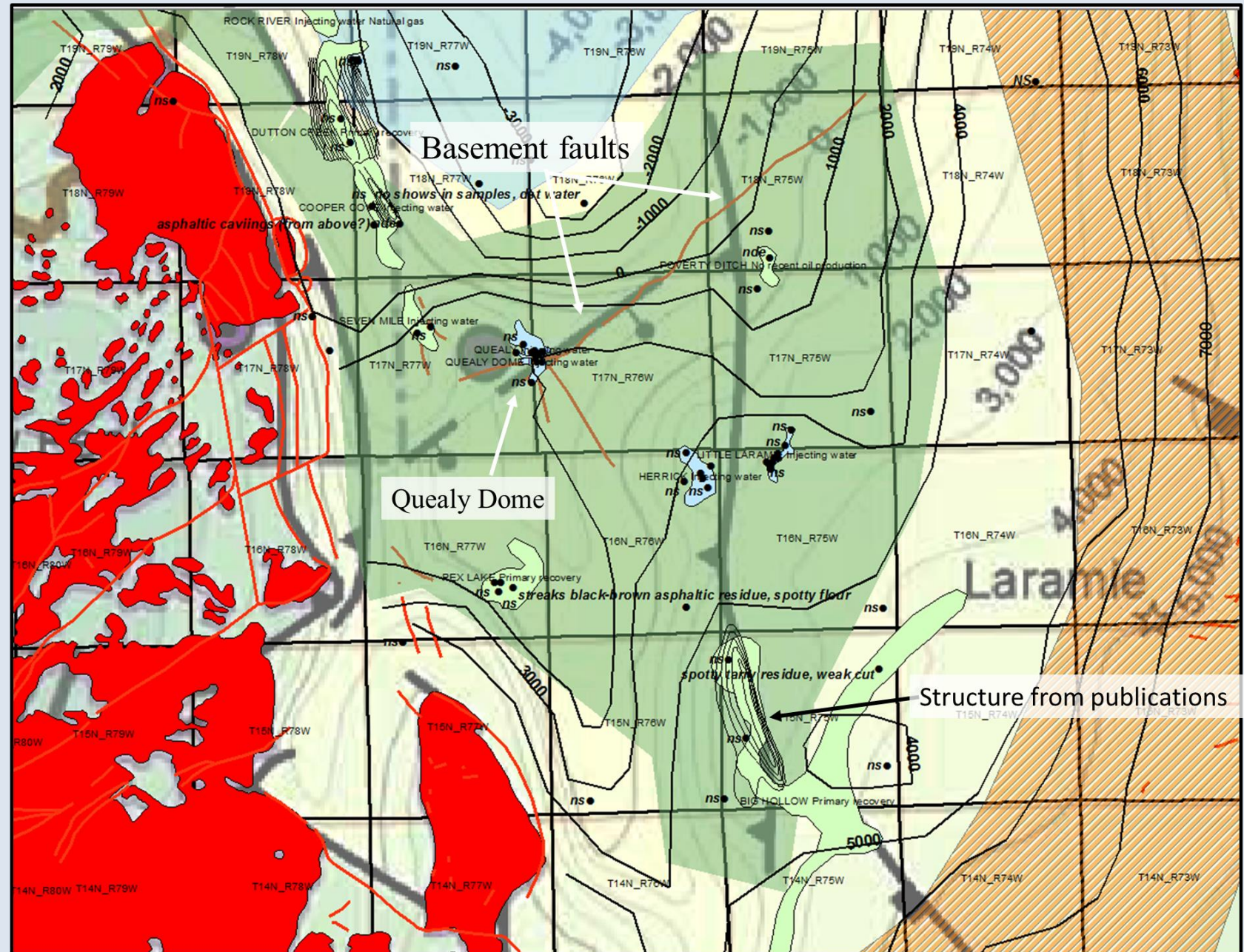
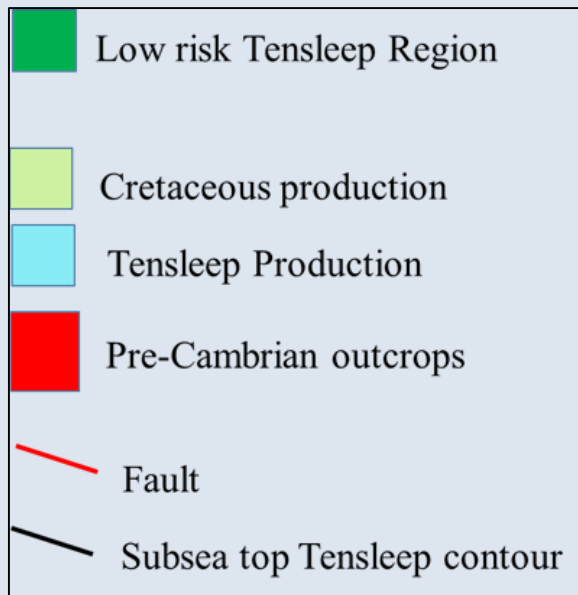
Trade seismic data in the SE Wyoming region. Black lines show 2D data, red polygons show 3D surveys. These data are superimposed on the combined CRS map for the region based on this study (see maps this page). Map in background is Wyoming Basement map. Seismic data courtesy of SEI Seismic Exchange data brokers in Houston and Denver.



 **Quealy Dome**

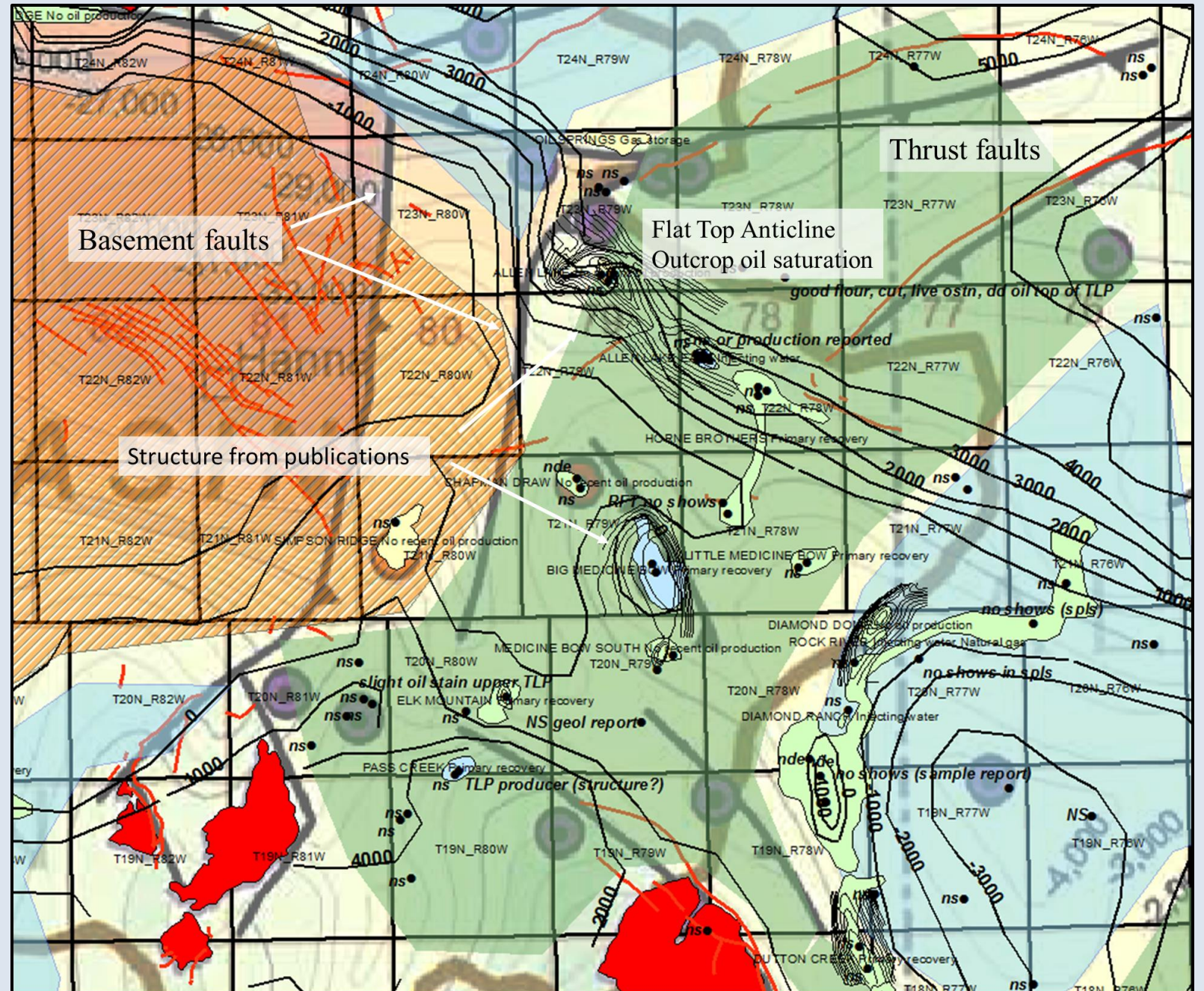
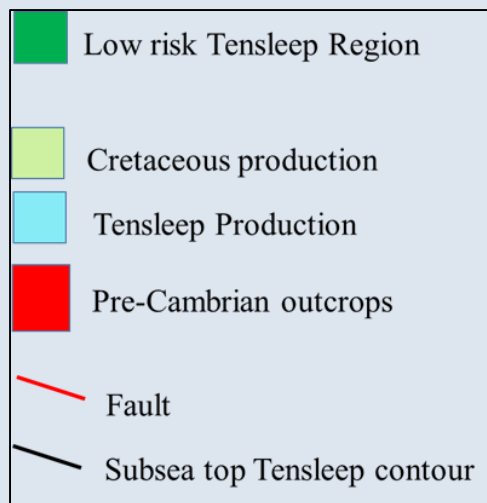
Quealy Dome

The Quealy Dome low-risk region is characterized by numerous free oil shows on drill stem tests. There is Tensleep production at Quealy Dome, Herrick and Little Laramie oil fields. The structuration - as visible on the Wyoming Geological Survey basement map, and on subsurface contours (based wells) - is complex. Undrilled anticlinal closures, overthrusts and fault traps may remain. The complexity noted by Stone (1995) is impressive, and one wonders if older seismic data has imaged this complexity properly.



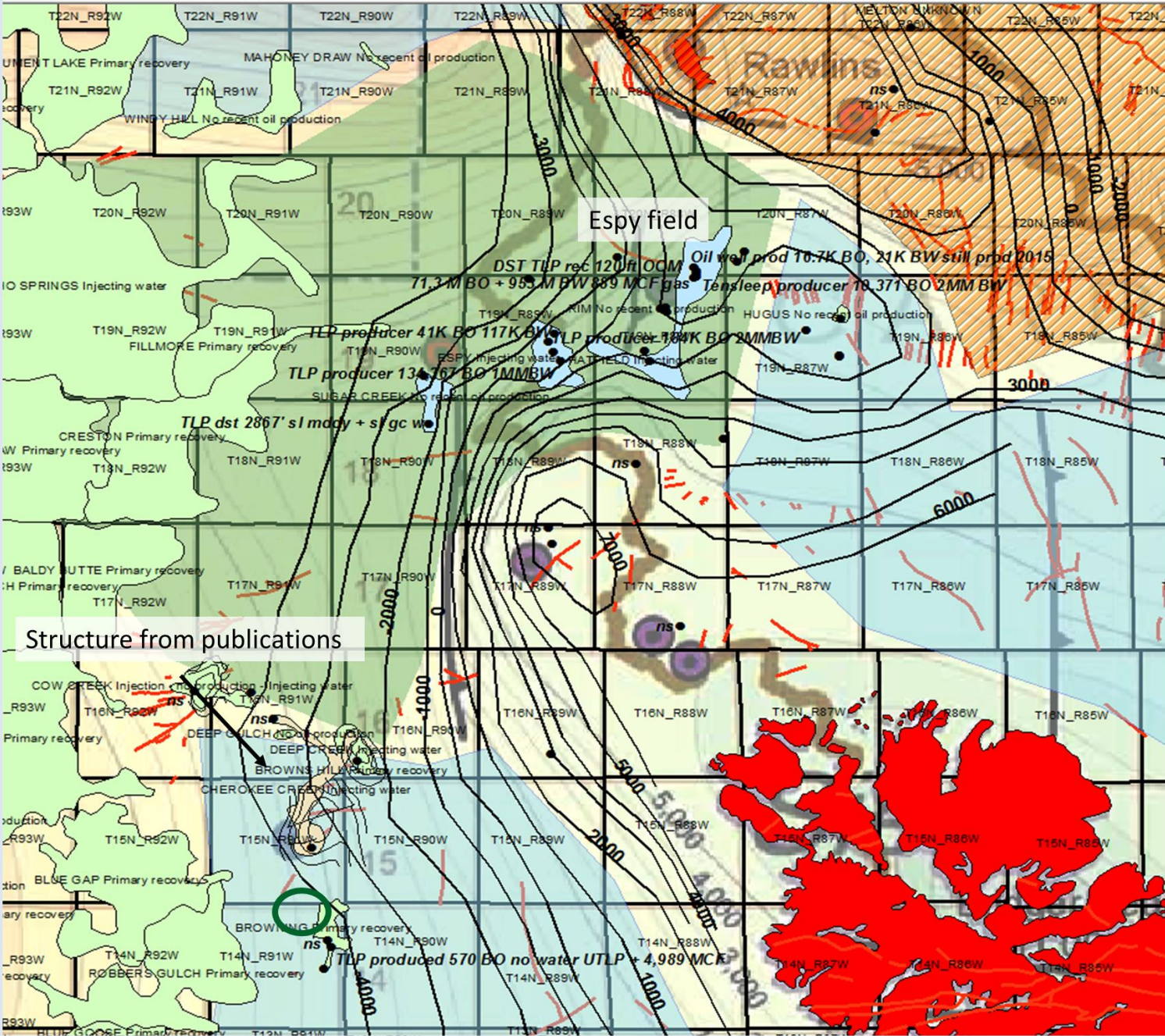
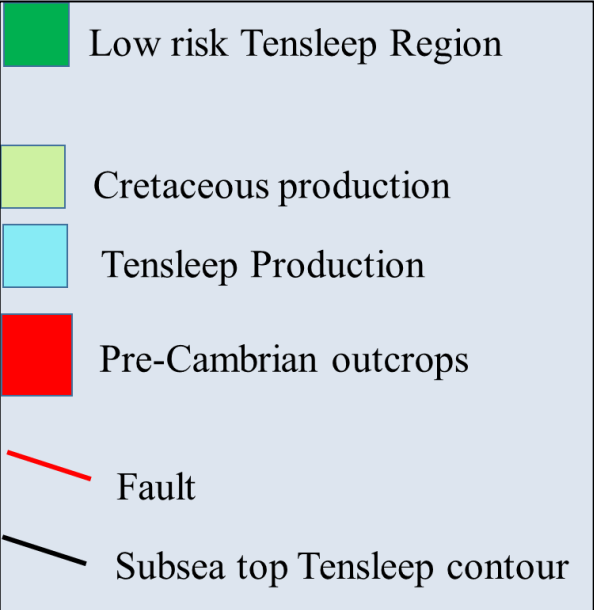
Big Medicine Bow

The Big Medicine Bow Low Risk area is characterized by both production and shows including the oil-saturated Tensleep outcrop at Flat Top Anticline. The area is defined by these factors as well as the structural ridge that separates it from the Hanna Basin to the west and a “pothole” basin to the southeast (see structural contours on map). Tensleep production is from Big Medicine Bow, Pass Creek and East Allen Lake oil fields on anticlines related to nearby faults. There are two sets of faults in the region – those that extend NW to SE in response to reverse thrusting from the Snowy Range, and others of more complexity related to basin boundaries and lateral components (near Flat top) of Snowy Range thrusts. The nearly orthogonal relationships of the anticlines in the area attests to the structural complexity of this region with very good shows and production.



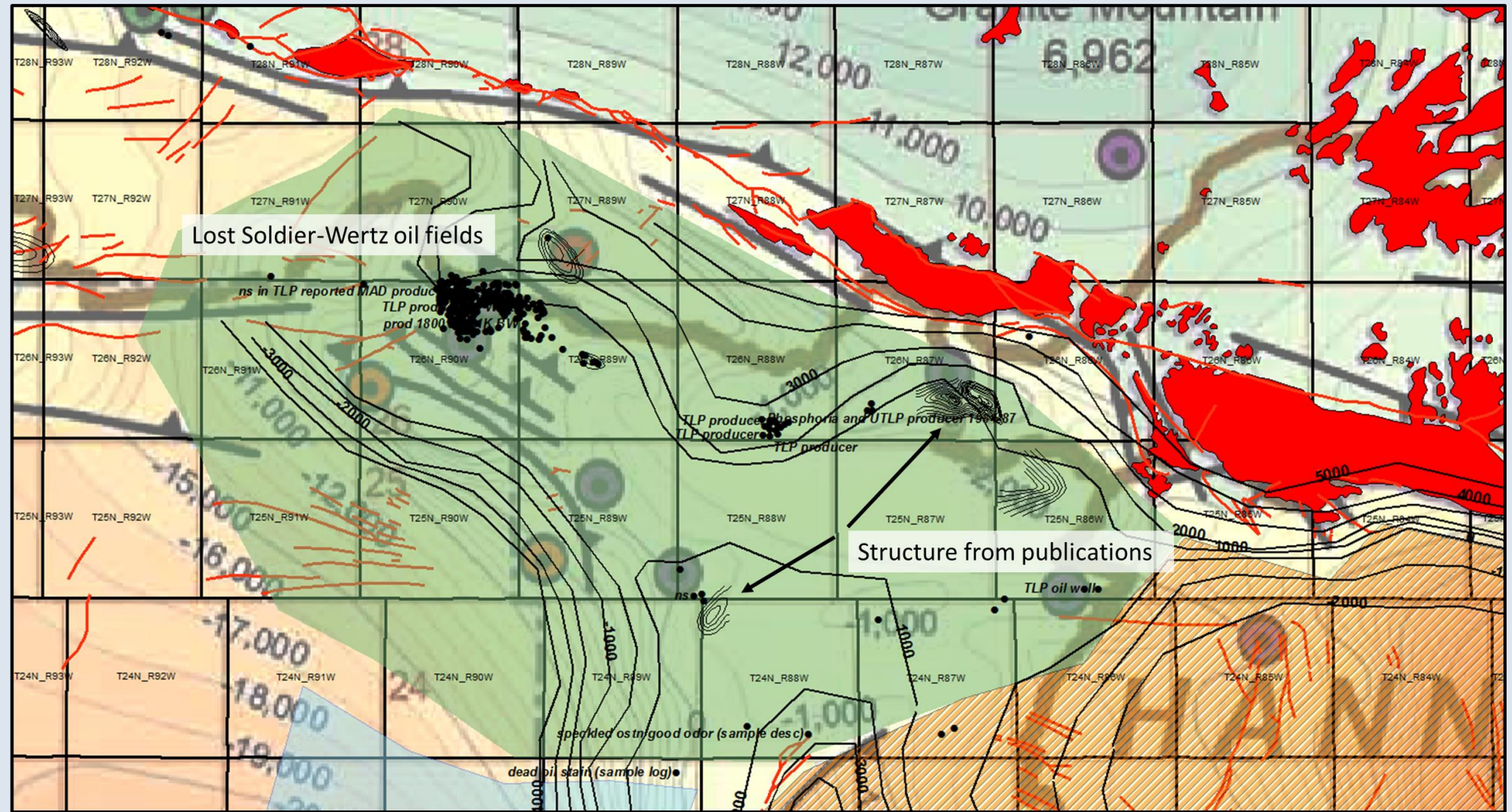
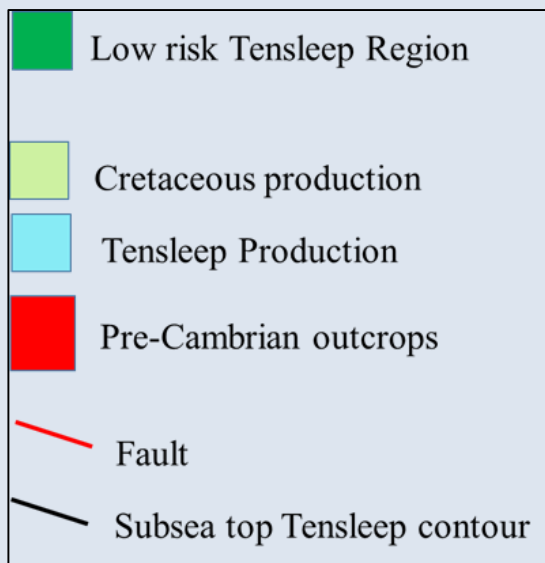
Espy-Atlantic Rim

The Espy-Atlantic Rim low risk region encompasses the Atlantic Rim Tensleep production and shows. Tensleep oil fields include Espy, Hatfield, Rim and Sugar Creek. The region may extend southward along the Sierra Madre structural nose – the Browning 1-13 in T14N R91W Upper Tensleep produced 570 BO and no water, a good show (green circle on map). Regional contours hint that there may in fact be better porosity with depth along the west flank of the Atlantic Rim. One drawback hampering exploration in this area is that the Tensleep tends to tighter than in other areas. Nevertheless, shows and production indicate good oil charge into the area if new structural closures can be found.



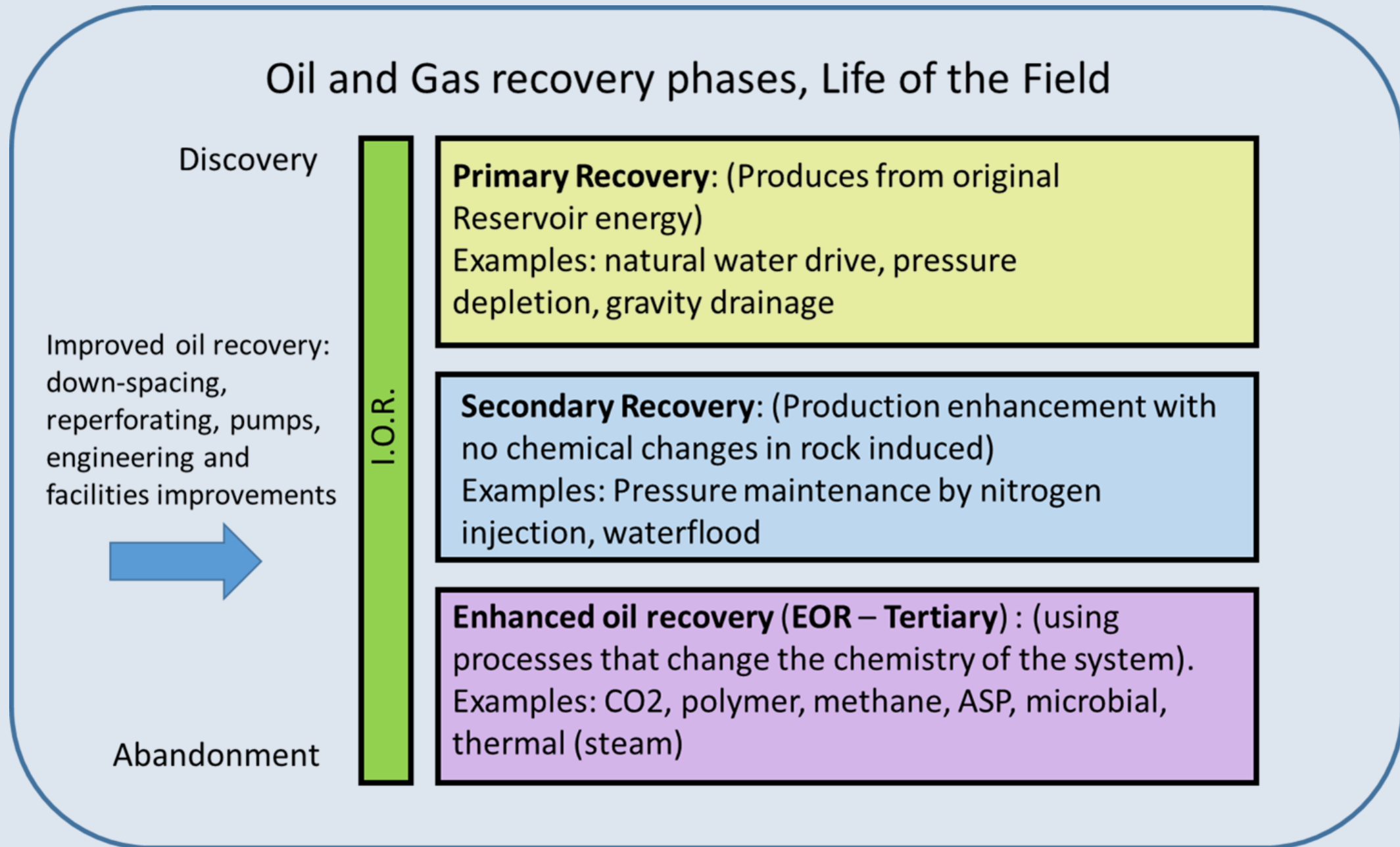
Lost Soldier-Wertz

The Lost Soldier-Wertz area is notable for those two very large Tensleep (+Madison) fields, as well as a few smaller ones. It is an interesting question whether there might be any significant undiscovered Tensleep accumulations in an area that has been so intensively explored. Probably this area, which is low risk, awaits the “new idea in an old area” concept. It might be worth a look at older seismic to make sure that processing and acquisition parameters are up to date, and that no prospective thrust faults have been overlooked.

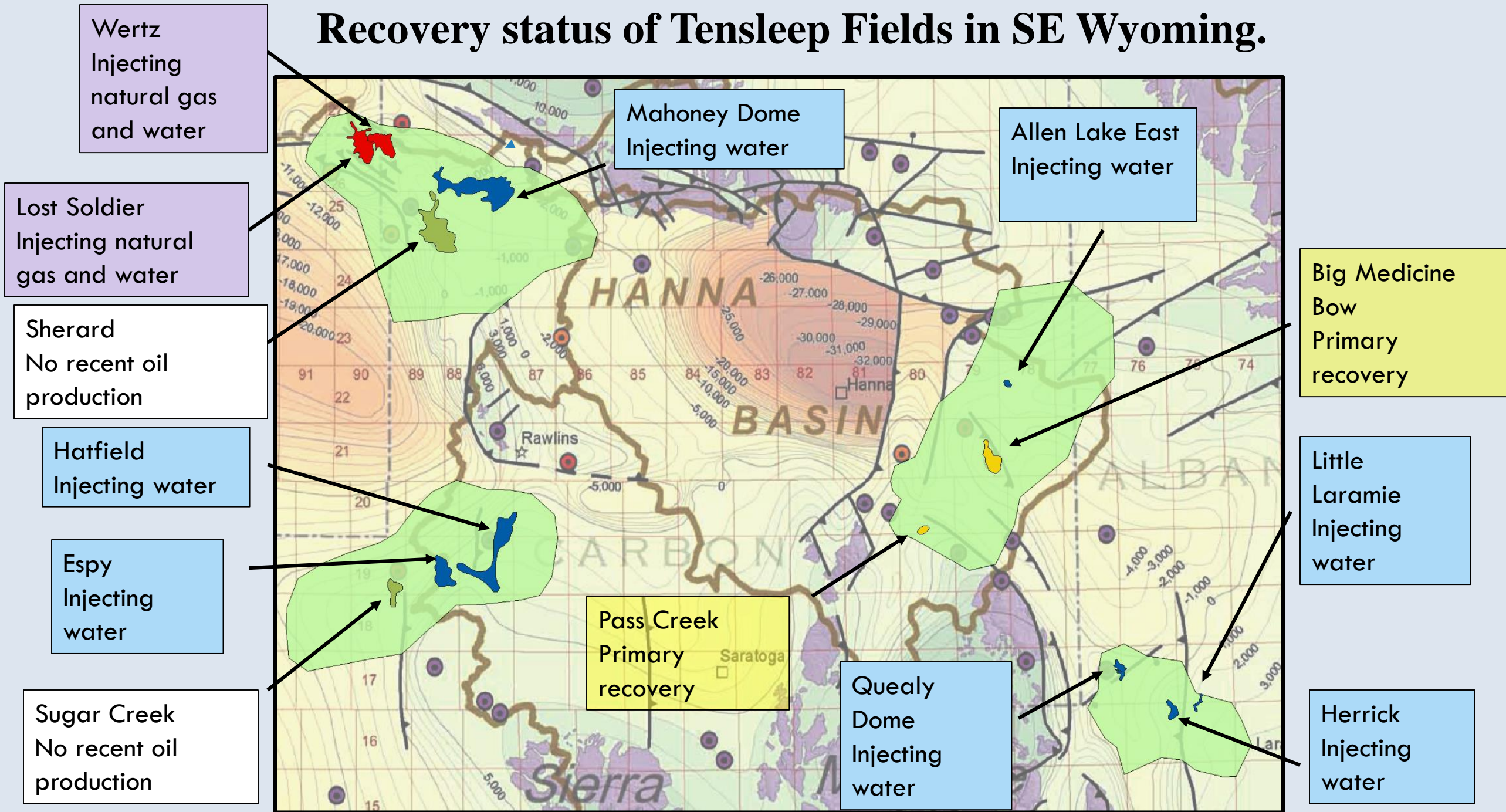


Recovery Terminology

Oil and Gas recovery phases, Life of the Field



Recovery status of Tensleep Fields in SE Wyoming.



Green shaded areas indicate regions of oil shows. Background: Basement map of Wyoming.

RESERVOIR DATA

Formation: Casper (Tensleep) - Pennsylvanian
 Lithology: Sandstone, light gray, fine-grained, hard and tite streaks
 Porosity: 16%
 Permeability: 140 md
 Average Pay Thickness: 130 feet
 Oil/Gas Column: 300 feet +
 Gas/Oil/Water Contact: +1870
 Gas Oil Ratio: 10 cu. ft./bbl.
 Initial Pressure: Unknown
 Present Pressure: Unknown
 Drive Mechanism: Water drive
 Rw and/or Salinity: Unknown
 Character of oil or gas: 27° API, sour (3% sulfur), 15°F pour point
 Continuity of Reservoir: Good
 Cumulative Production: 6,145,600 BO
 STBO or MCF/AC FT: 107 STBO AC/FT
 Secondary: Waterflooded since 1966
 Estimated Ultimate Primary: 6,200,000 BO (includes secondary)

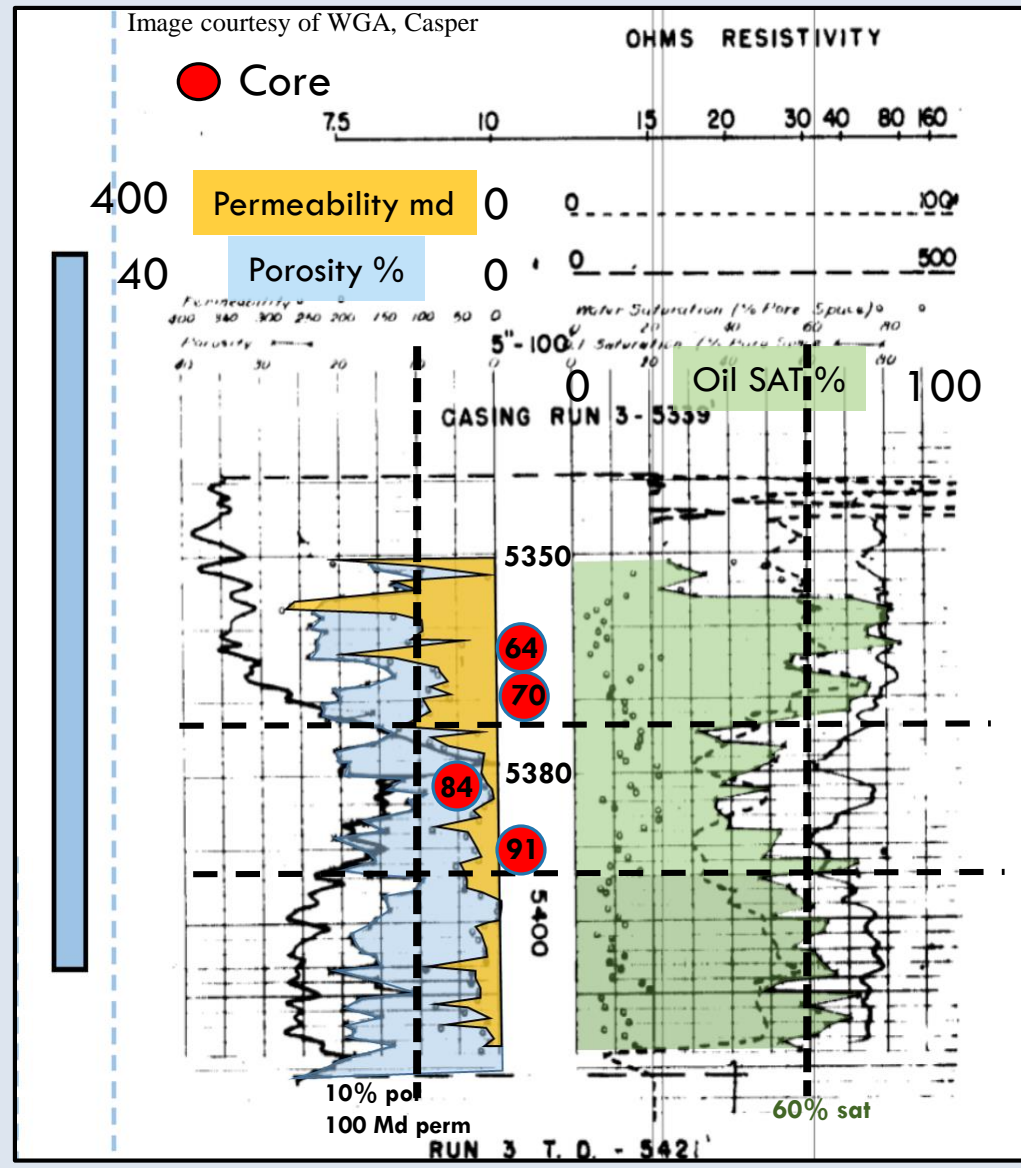
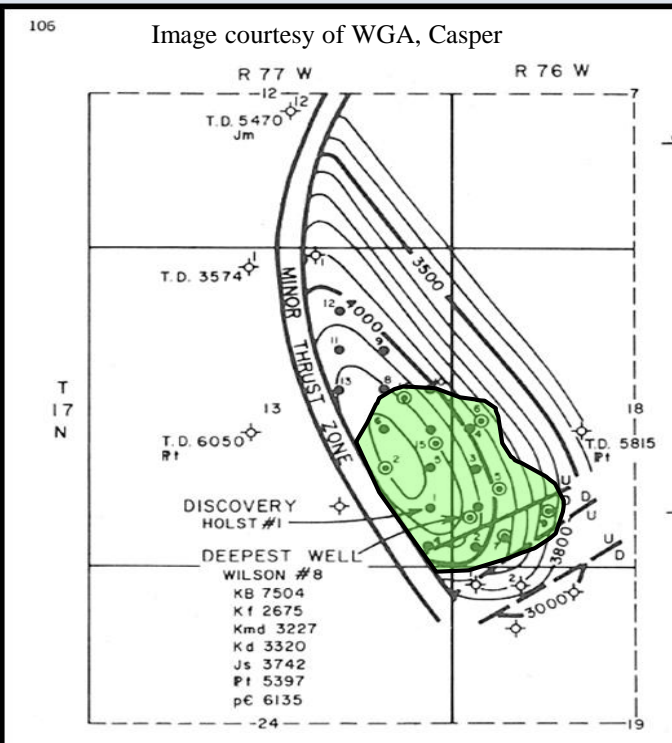
Tensleep producing area



Quealy Dome Oil Field

Have eolian genetic units and primary strata reduced recovery factor, and is there bypassed oil as a result?

49-001-05146
 LEGACY RESERVES OPERATING LP
 WILSON 6 QUEALY
 2435 FSL AND 405 FWL (NW SW) 18
 17 NORTH 76 WEST
 41.445523 -105.981398

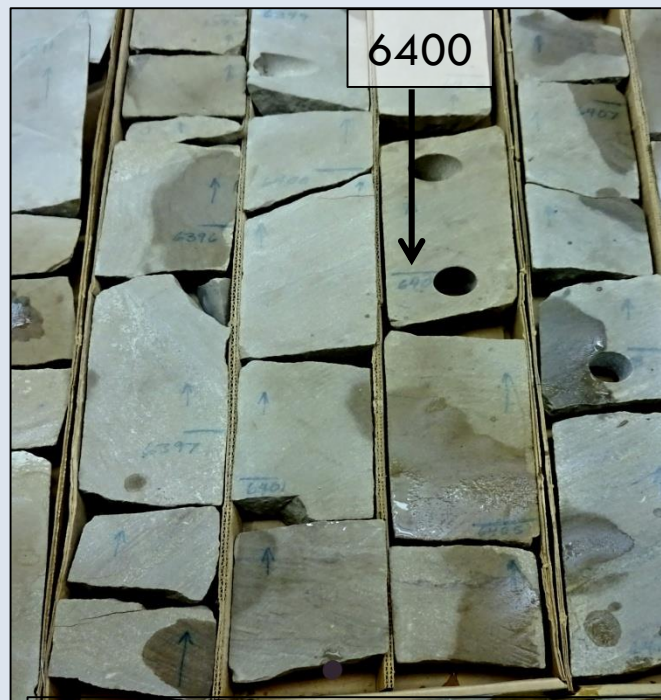
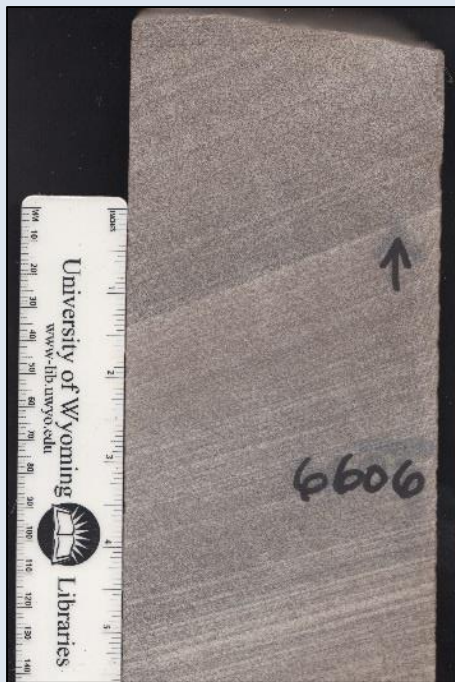


Wilson 6 Quealy Dome has Avalanche and ripple primary eolian strata in all zones.

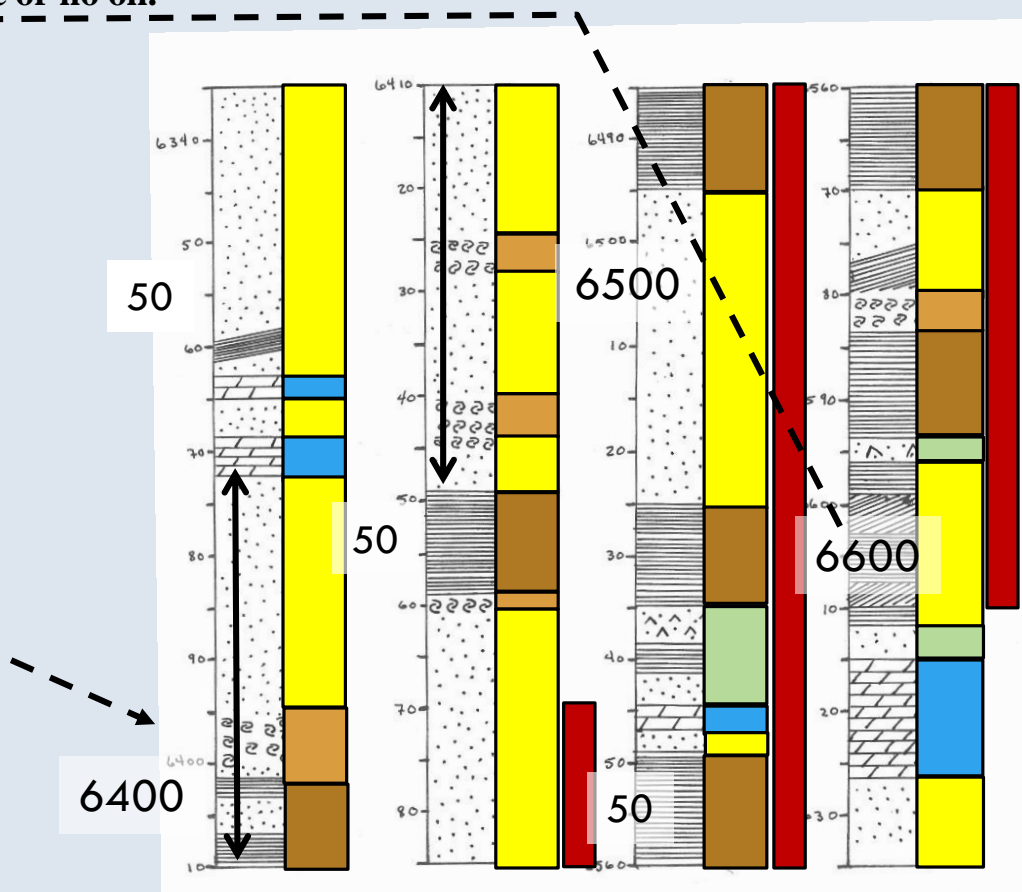
WERTZ 46

An Upper Tensleep genetic unit was left unperforated, despite high oil saturation. Oil may have been swept by an adjacent injection-producer well, or not displaced. Unit appears stratigraphically isolated from perforated unit below

Eolian avalanche and ripple primary strata, note the white laminations with little or no oil.



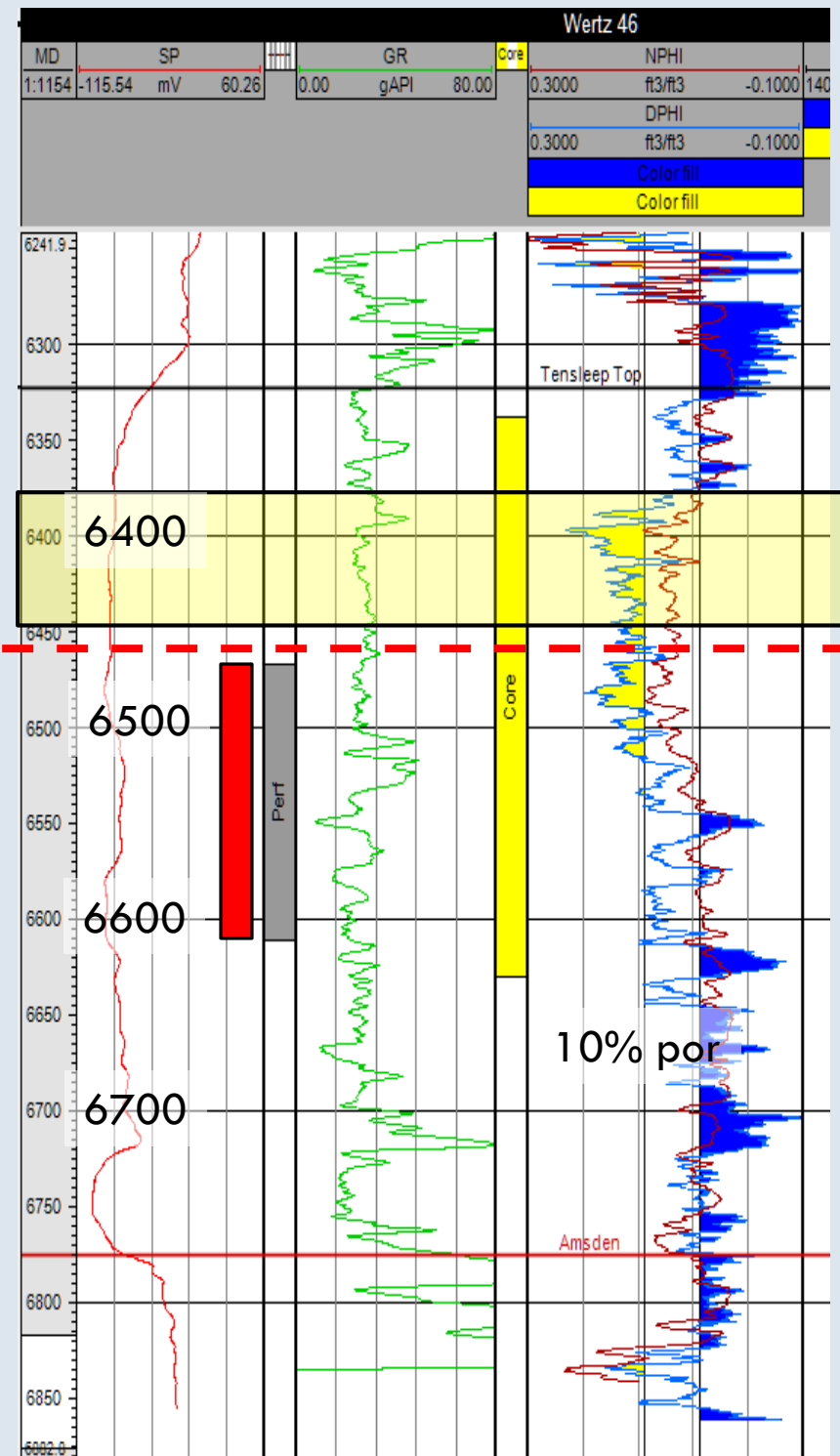
Faint eolian primary strata in oil saturated core are visible in this image core from Wertz 46.



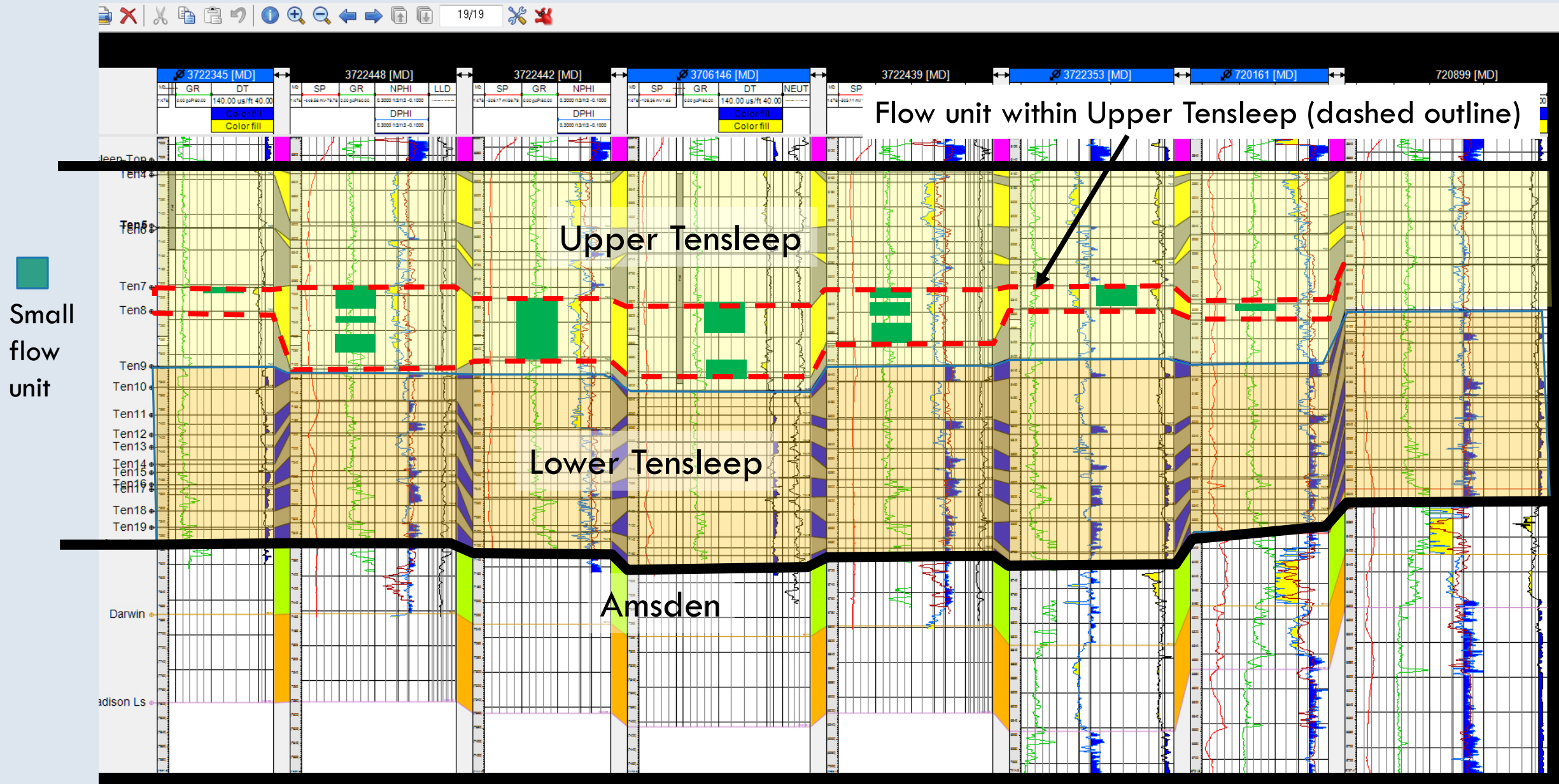
Facies

- Eolian Dune
- Sandsheet
- Marine
- Interdune
- Sabkha
- Perforations

Fryberger, Jones and Johnson 2016

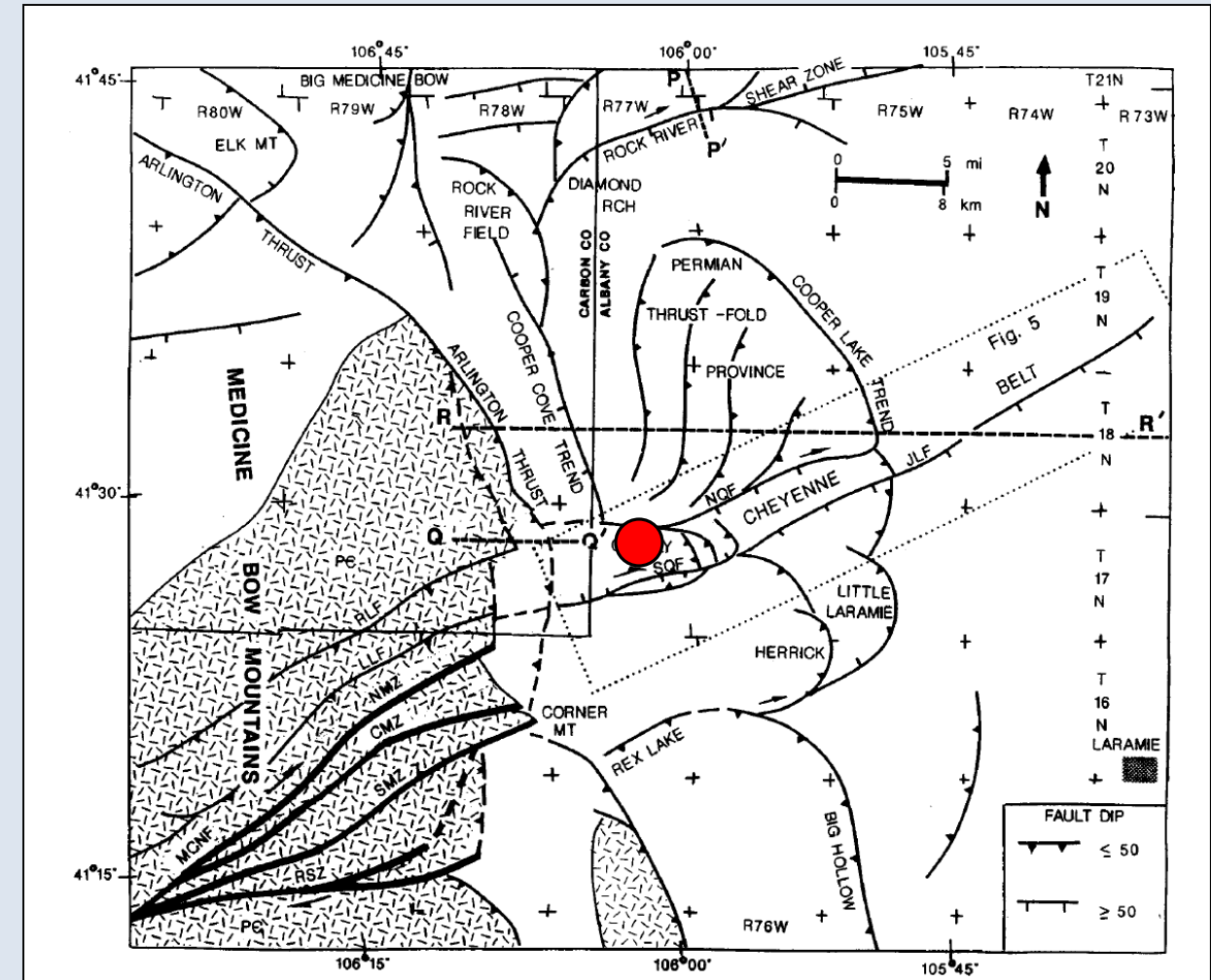
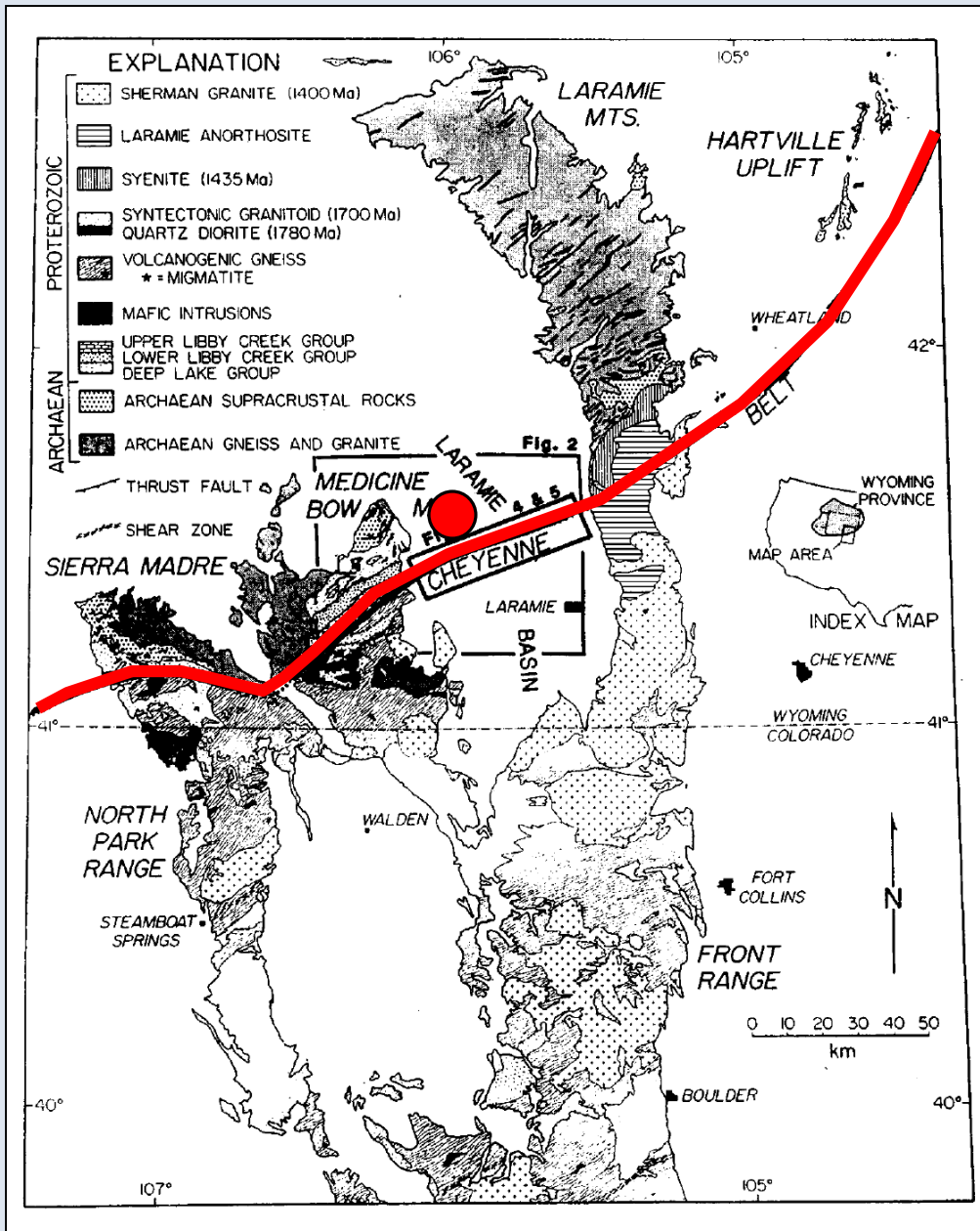


Petrel static model showing Lower and Upper Tensleep at Wertz Oil Field



Lower and Upper Tensleep stratigraphy is evident in the Petrel static model created by Matt Johnson at Wertz Oil Field. Complex flow units above the level of primary strata exist in the Upper Tensleep, as marked. The Lower Tensleep is far more difficult to produce because there are more genetic units (flow units) divided by impermeable rock, and more effects of primary strata break up the reservoir into many compartments. This is both a problem, and an opportunity for IOR/IOV planning.

Structural concepts in the Laramie-Hanna Basins



Precambrian geology along the Cheyenne belt (heavy black line) in southeast Wyoming (modified after Johnson et al., 1984). The two rectangles outline map areas shown in figure on this and next page. The Cheyenne belt is a suture zone separating the Wyoming Archean province on the north from the Colorado Proterozoic province on the south.

Basement faults of the Laramie Basin and mylonite zones of the Cheyenne belt in the Medicine Bow Mountains. (area shown as "Figure 2" on map at left). RLF= Reservoir Lake fault; LLF = Lewis Lake Fault; NMZ = Northern Mylonite Zone; CMZ = Central mylonite zone; SMZ = Southern Mylonite Zone (former name for the Cheyenne belt); SQF = South Quealy fault; NQF = North Quealy fault; JLF = James Lake fault; PC with pattern = Pre-Cambrian outcrop (undiff). Dotted rectangle is mapped are in Figures 5 and 6, PP', QQ' and RR' are structural cross section locations in Stone, not used in this talk.

Figures after Stone, 1995

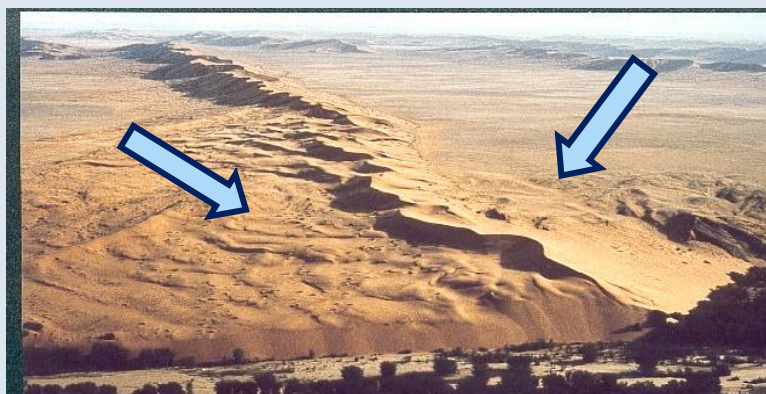
Modern and Ancient analogues:

Basic Dune Types vary in geometry and abundance of ripple and avalanche primary strata; which affect reservoir performance.

After Fryberger, 1979



Barchanoid – 1 wind direction

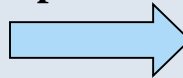


Linear – 2 main wind Directions



Star – 3 main wind Directions

Dune types depend upon wind direction

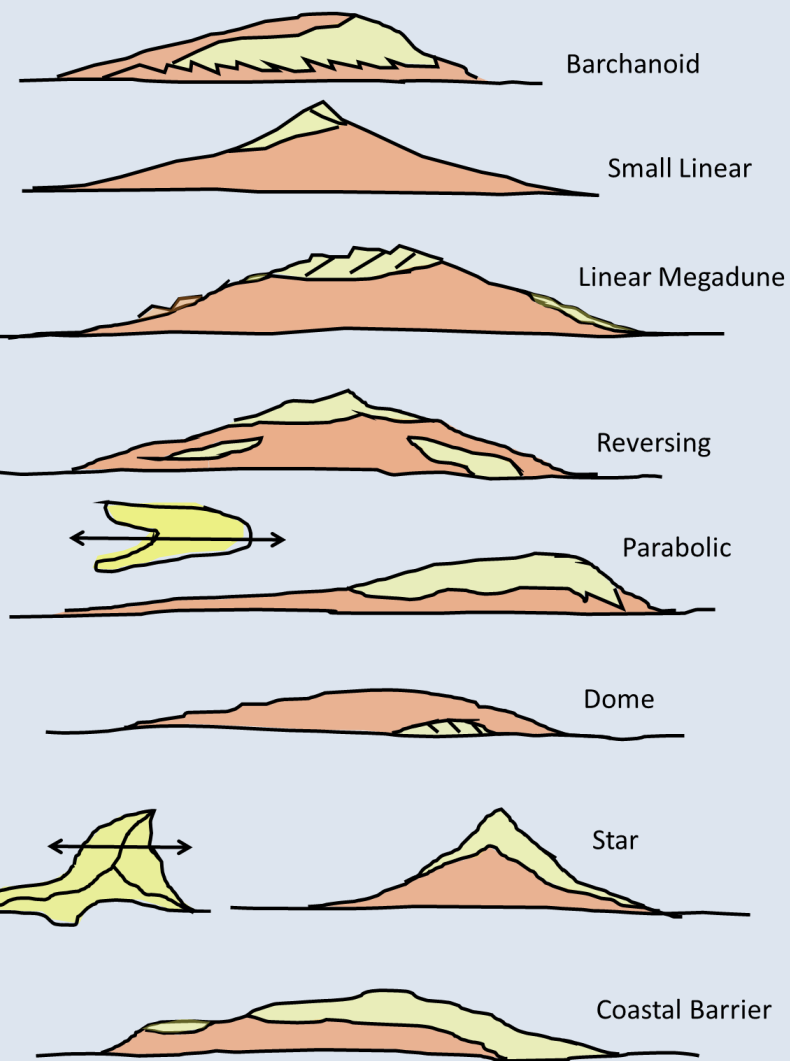


Modern Analogues:
Eolian dune type and formative wind regime create complex, but distinctive patterns of primary strata with eolian rocks.

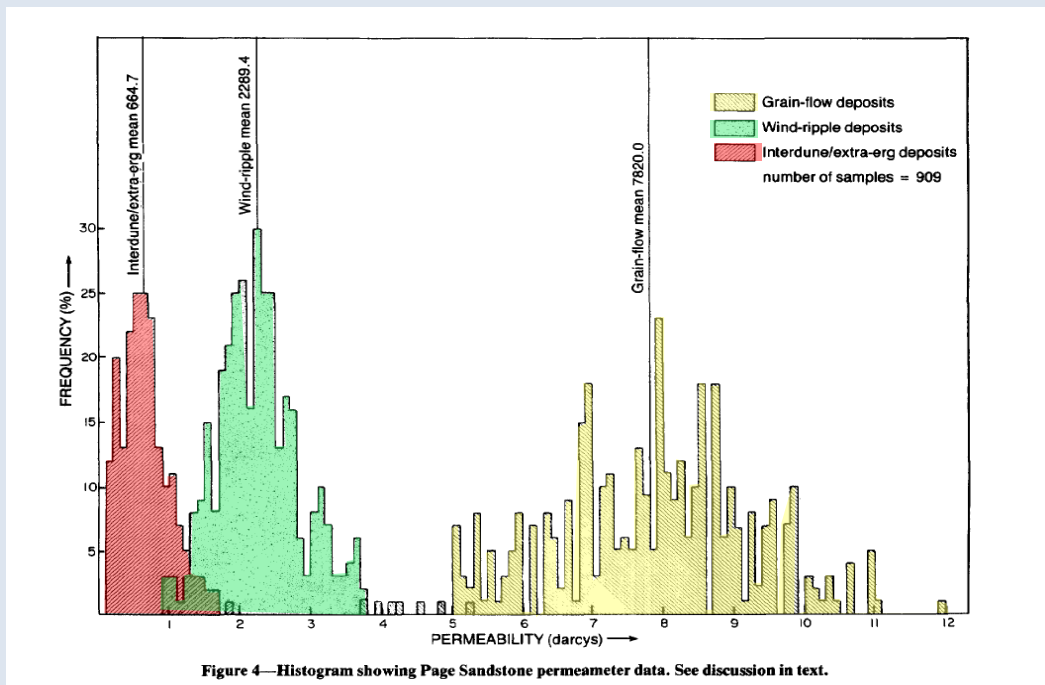
Yellow Avalanche strata best reservoir

Orange: Ripple strata, poor reservoir

Dune Types: Schematic proportions of Ripple and Avalanche Strata



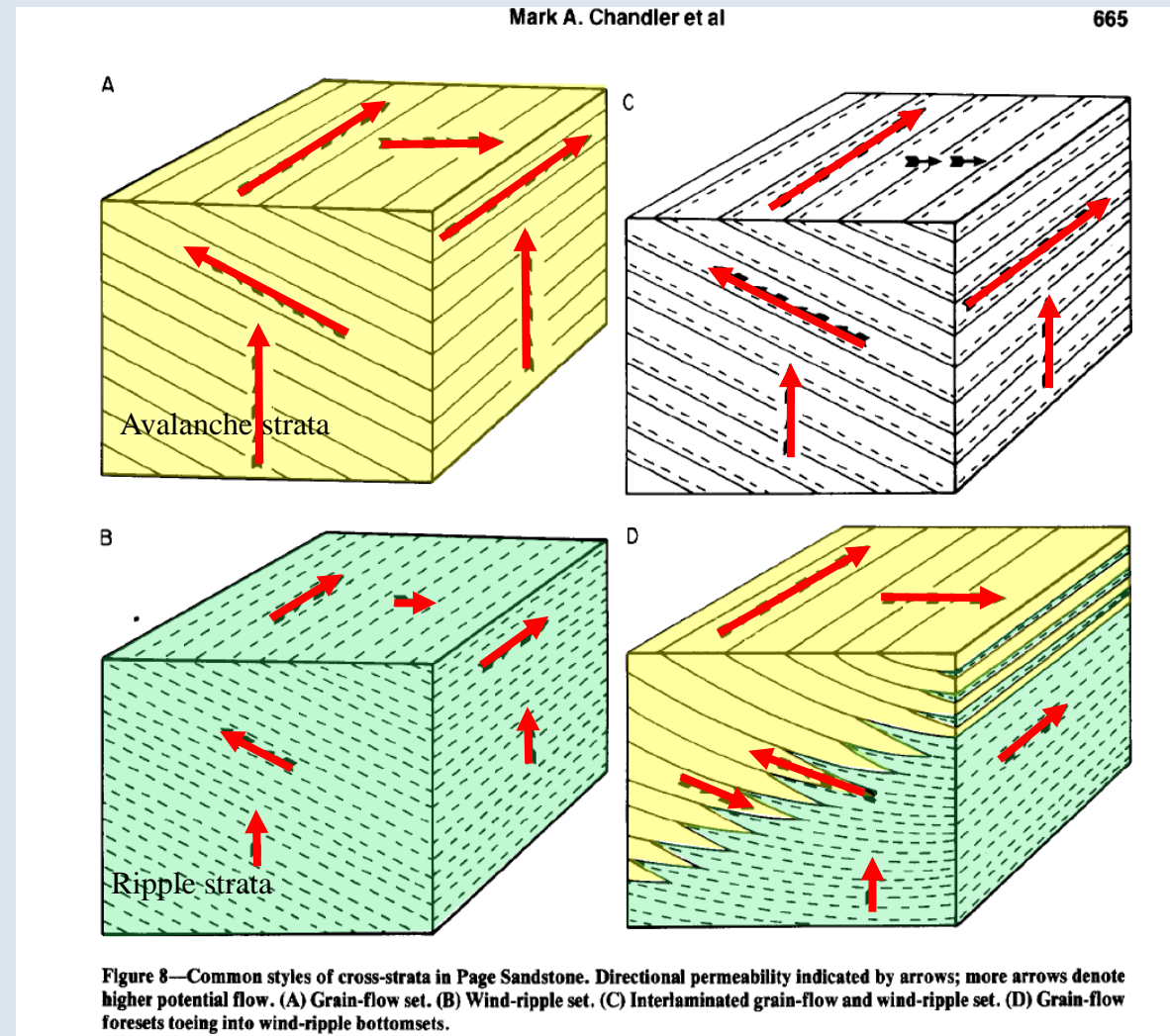
Modern and Ancient analogues for eolian reservoirs



Permeability variations from Page Sandstone outcrops in Northern Arizona. There is about one order of magnitude difference in permeability between “interdune” and “grain flow (avalanche)” deposits in the outcrop. Contrast tends to be greater in the subsurface! After Chandler, et al 1989



Page Sandstone outcrop at Page, Arizona, viewed by geologists on a Shell Field trip.

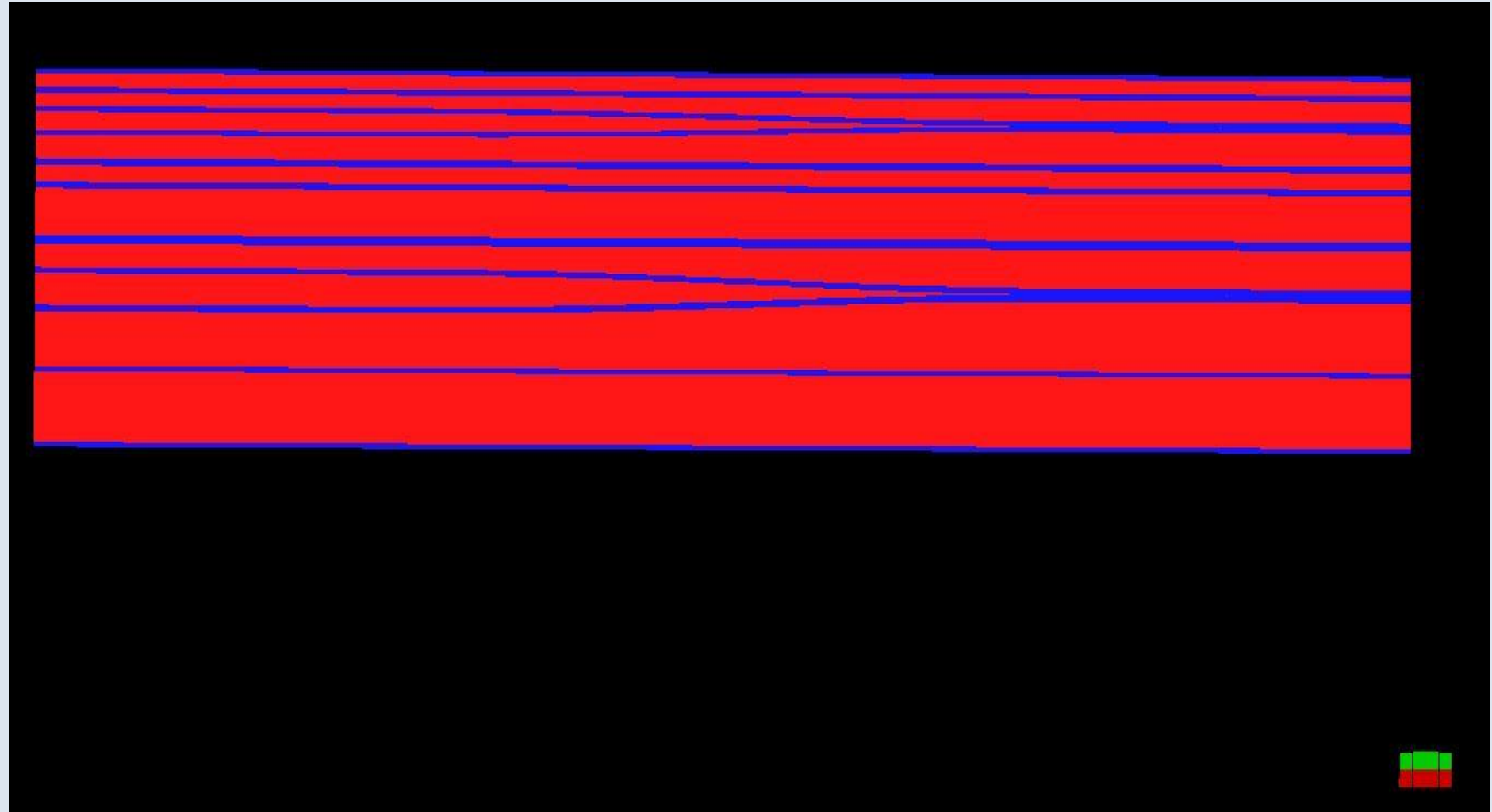
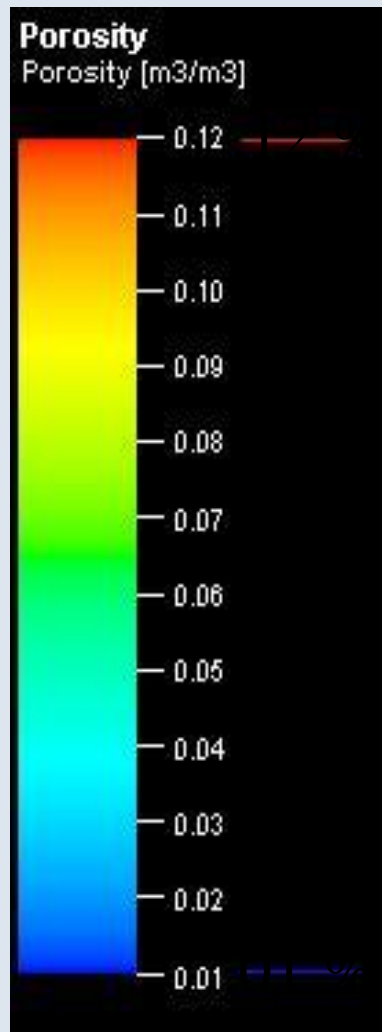


Preferred flow direction and permeability at small (laminar) scale in avalanche and ripple strata. These are predicted from minipermeameter measurements in Jurassic Entrada Sandstone. Red arrows are proportional in length to directional permeability along primary strata. After Chandler, et al 1989

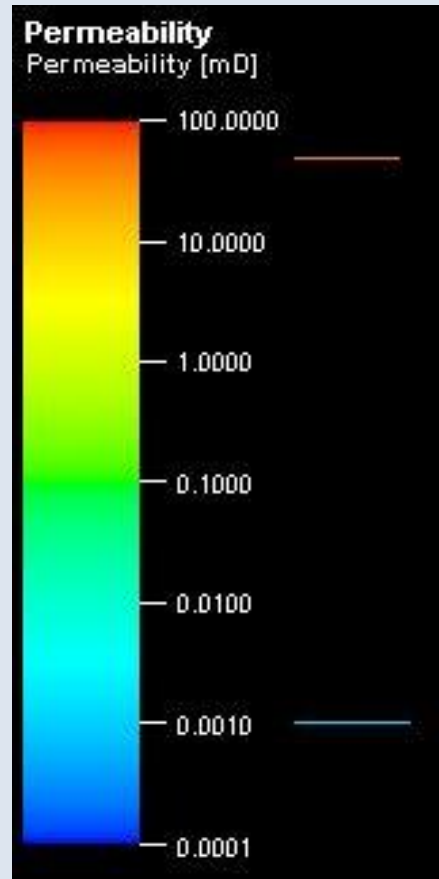
Oil flow through eolian ripple strata: A Model

By Zahn Wang and Matt Johnson

POROSITY DISTRIBUTION

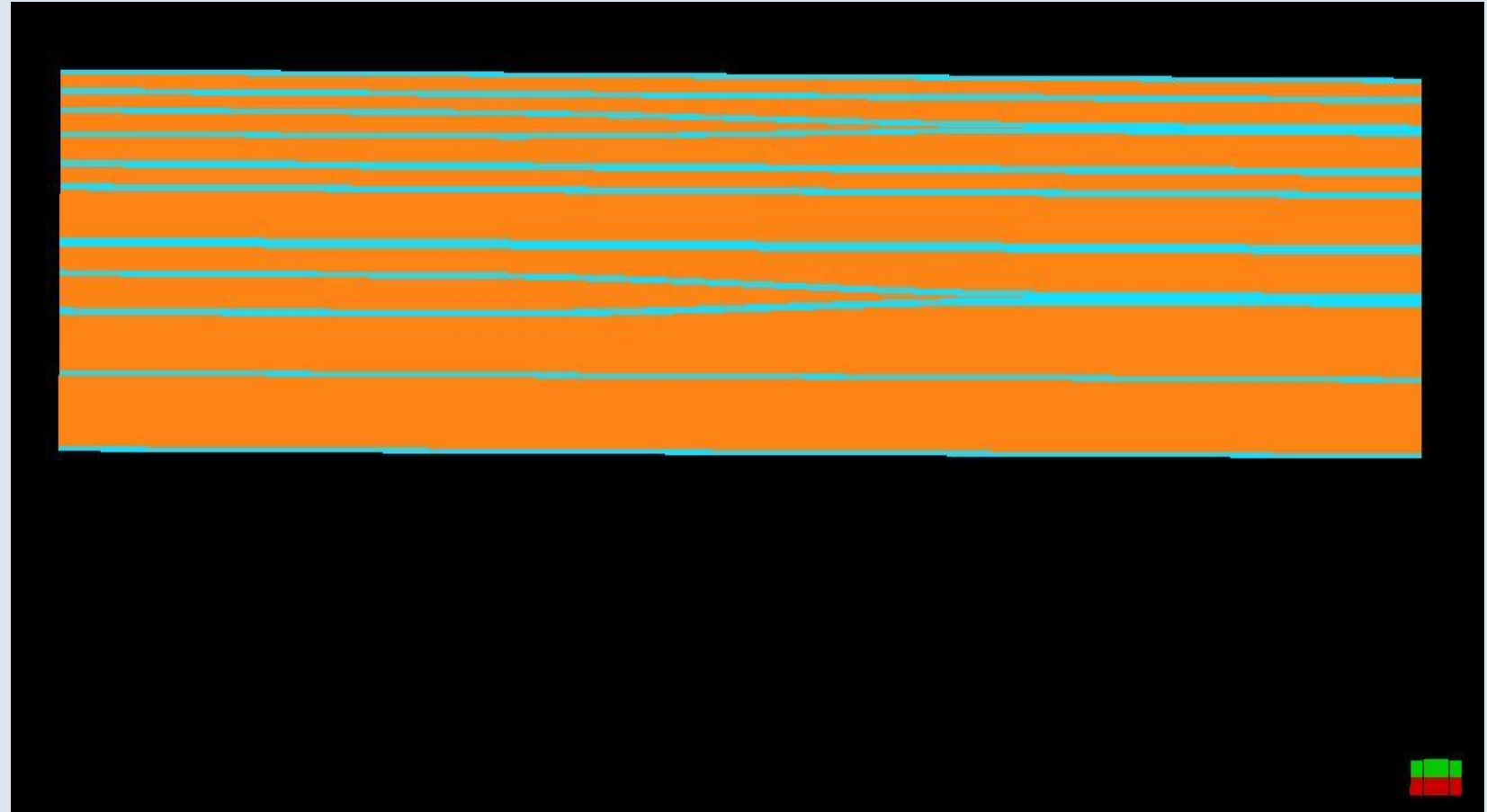


PERMEABILITY DISTRIBUTION



MD

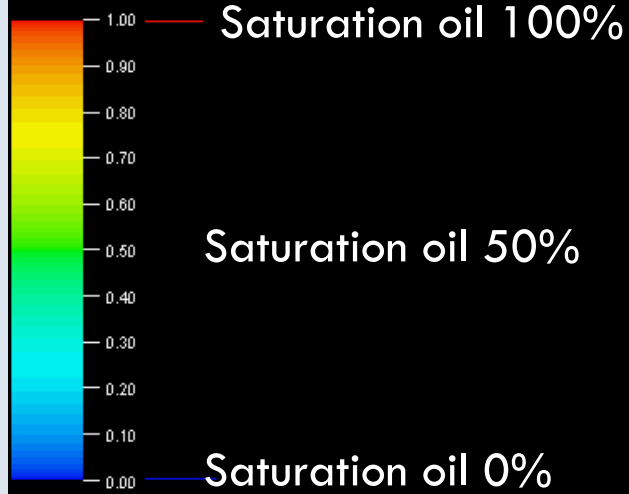
MD



A Digital model of oil flow through eolian ripple strata

By Zahn Wang and Matt Johnson

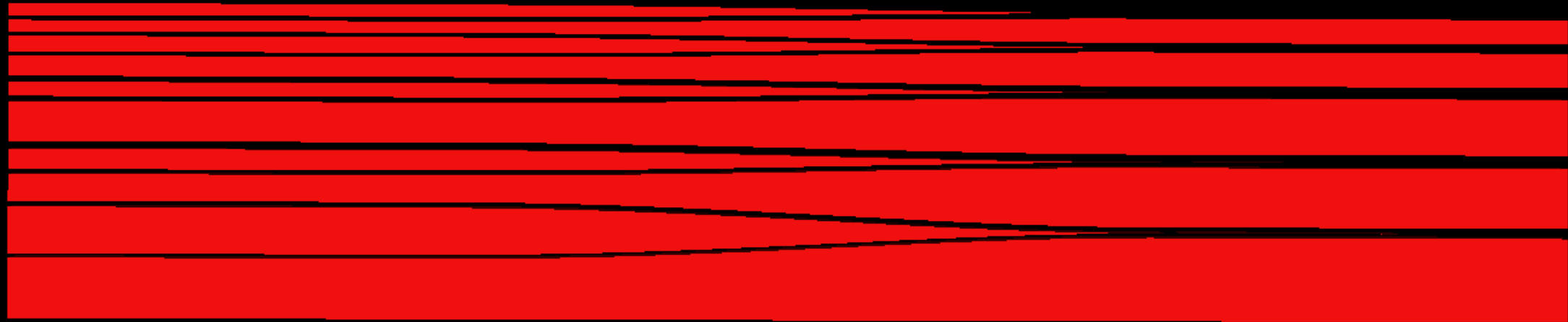
SOIL[0] [Jan 01,2015]
Oil saturation



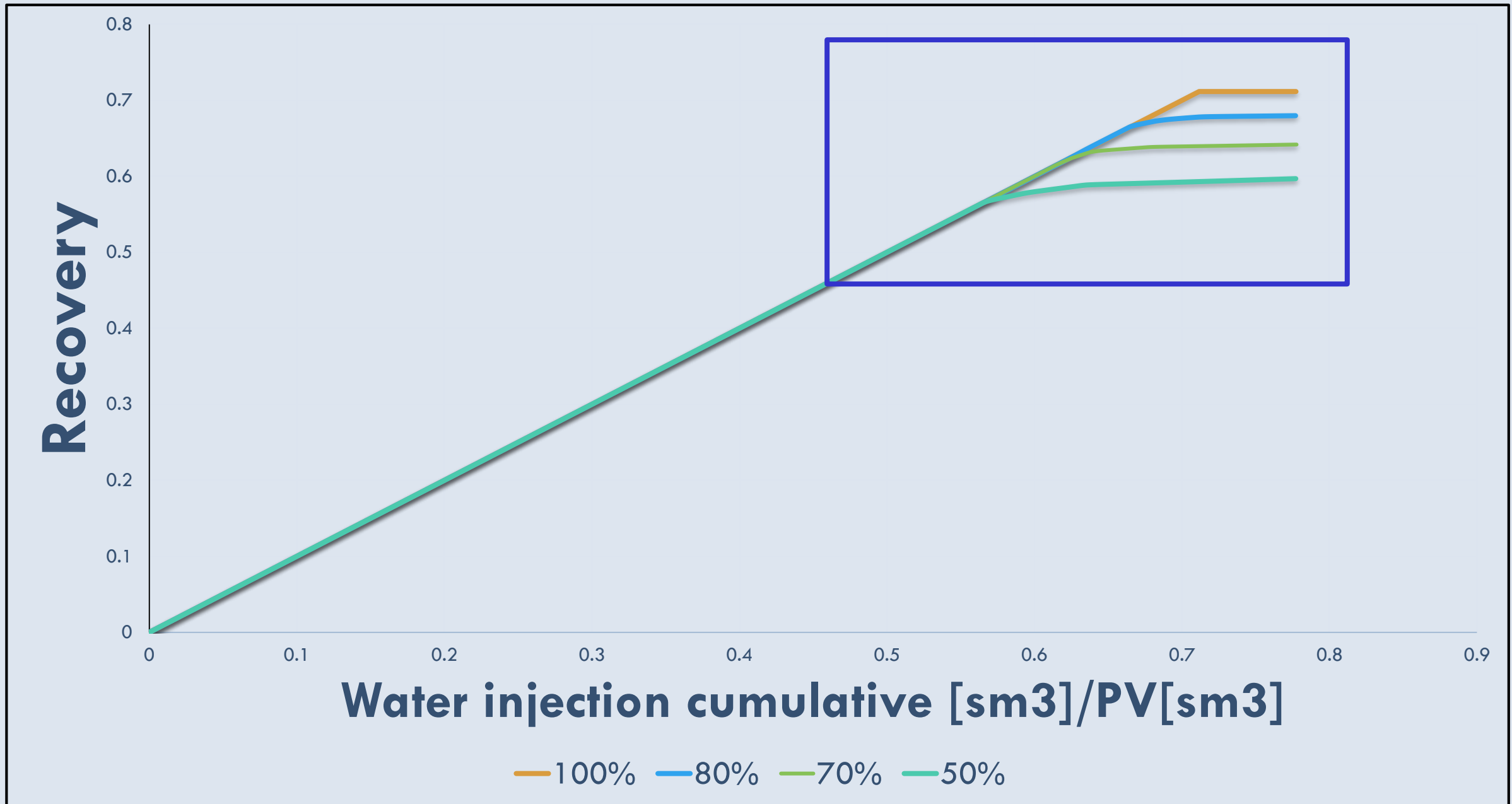
46 Wertz NESESW 1 26N 90W 6607.5



Eolian ripple strata on a reversing dune in the Killpecker dune field, Wyoming



Recovery Factors from the models



Conclusions: Stratigraphy

- **The Tensleep and Casper Formations comprise the same rocks in SE Wyoming.**
- **The Tensleep Formation in SE Wyoming can be divided into an eolian Upper Tensleep member and a carbonate-rich paralic and eolian Lower Tensleep Member.**
- **The Upper Tensleep is mainly Permian, the Lower Tensleep is Carboniferous. Lithological change between Upper and Lower Tensleep was probably driven by increasing aridity from Upper Carboniferous time into Permian times. We did not find a disconformity between the two members.**
- **The Fountain Formation commonly intercalates with the Lower Tensleep, close to older uplifts such as the Front Range.**
- **Oil Production in Southeast Wyoming Tensleep is mainly from the Upper Tensleep in anticlinal structural traps.**
- **Shallow marine carbonates intercalate with the Upper Tensleep (Permian) along the Laramie Range.**



Conclusions: Petroleum Exploration and Production

- **Common Risk Segment maps of SE Wyoming Tensleep oil shows, structure and reservoir quality has identified four regions near existing production that may have opportunities for further exploration using improvements in exploration technology.**
- **Oil production in SE Wyoming occurs in a variety of stages from primary through tertiary (EOR), as well as various states of IOR (mechanical upgrades). There may be development opportunities in some existing fields using a combination of modern EOR/IOR techniques and new seismic data.**
- **The State of Wyoming well database is a valuable asset, but is not usable for exploration work without revision of tops. We used this trove to create a revised database of tops and other data that updates older (historical) tops in the State of Wyoming database, using modern stratigraphic concepts and the ESRI ArcGIS platform.**
- **Much oil in the Tensleep may be trapped in microscopic stratigraphic traps created by primary eolian strata, and in complex flow units derived from the stacking small dunes or eolian facies groups of dune, interdune, sand sheet and sabkha.**
- **It may be possible to calculate recovery factors for oil trapped in primary strata, and devise ways to produce it.**



REFERENCES CITED

- Agatston, R.S., 1954, *Pennsylvanian and Lower Permian of Northern and Eastern Wyoming*, A.A.P.G. Bulletin, v. 38, p. 508-583.
- Benniran, M.M., 1969, *Casper Formation Limestones, Southwestern Laramie Mountains, Albany County, Wyoming*, M.S. Thesis, University of Wyoming, Laramie, 95 pp.
- Blackstone, D.L., Jr., 1989, *Precambrian basement map of Wyoming—Outcrop and structural configuration*: Geological Survey of Wyoming [Wyoming State Geological Survey] Map Series 27, 1 sheet, scale 1:1,000,000
- Chandler, M.A., et al, 1989, *Effects of Stratigraphic Heterogeneity on Permeability in Eolian Sandstone Sequence, Page Sandstone, Northern Arizona*, A.A.P.G. Bulletin, v. 73, p. 658-668.
- De Bruin, R.H., and Hostetler, S.D., 1993, *Oil and gas fields map of southeastern Wyoming basins*: Geological Survey of Wyoming [Wyoming State Geological Survey] Map Series 42, 1 sheet, scale 1:316,800.
- De Jager, J., and Stephen Wright, 2006, *Play-Based Exploration to Improve Performance*, Abstract #90061 AAPG Search and Discovery.com in AAPG Datapages combined publications database.
- Foster, D.I., 1958, *Summary of the Stratigraphy of the Minnelusa Formation, Powder River Basin, Wyoming*, in 13th Annual Field Conference Guidebook, Powder River Basin of Wyoming, Wyoming Geological Association, Casper, Wyoming, p. 39-44.
- Fryberger, S.G., 1979, *Dune Forms and Wind Regime*, Chap. F, in McKee, E.D. editor, *A study of Global Sand Seas*, USGS Professional Paper 1052.
- Kelly, A. O., 1984, *Significance of interdune deposits in the Upper Casper Formation*, in 35th Annual Field Conference Guidebook, Wyoming Geological Association p. 97-110.
- McKee E.D. and Oriel, S.S., et al, 1967, *Paleotectonic Investigations of the Permian System in the United States*, U.S. Geological Survey Professional paper 515, 271 pp.
- Potter, E.C., 1984, *Quealy Dome*, in *Symposium on Wyoming Oil and Gas Fields - Laramie, Hanna and DJ Basins: Casper, Wyoming*, Wyoming Geological Association, p. 106-108.
- Shell Exploration and Production, 2006, *Play Based Exploration: A Guide for AAPG's Imperial Barrel Award Participants*, 52 pp.
- Stone, D.S., 1995, *Structure and Kinematic Genesis of the Quealy Wrench Duplex: Transpressional Reactivation of the Precambrian Cheyenne Belt in the Laramie Basin, Wyoming*, AAPG Bulletin, v. 79, p. 1349-1376.,
- Trewin, N., Fryberger, S.G. and Kreutz, H., 2003, *The Auk Field, Block 30/16, UK North Sea*, in *Gluyas, J.G. and Hitchens, H.M. (eds) 2003, United Kingdom Oil and Gas fields*, Commemorative Millennium Volume; Geological Society, London, Memoir 20, p. 485-496.
- Weber, K.J., 1987, *Computation of Initial Well Productivities in Aeolian Sandstone on the basis of a Geological Model, Leman Gas Field, U.K.* in *Society of Economic Paleontologists and Mineralogists (SEPM) Special Publication 40, Reservoir Sedimentology* p. 333-354.