Stratigraphy, Exploration and EOR potential of the Tensleep/Casper Formations, SE Wyoming*

Steven G. Fryberger¹, Nick Jones², Matthew Johnson², and Curtis Chopping²

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¹Present: Steven Fryberger Petroleum, Laramie, Wyoming (steve.fryberger@gmail.com)
²Enhanced Oil Recovery Institute, University of Wyoming, Laramie

Abstract

The first theme of this poster presentation is to provide an update on the stratigraphy and sedimentology of the Tensleep/Casper Formation of Southeast Wyoming (and parts of Northern Colorado), and oil production from these rocks. We incorporate new measured sections, stratigraphic analysis and petrographic work undertaken by the authors. To this end we created a new database in ArcGIS (geographic information software) of tops and other information that updates the historical well database of the Wyoming Oil and Gas Commission archived in Casper. This new database has been used to create Common Risk Segment (CRS) maps of the Upper Tensleep oil play segment in Southeast Wyoming. These CRS maps indicate trends in Tensleep reservoir, charge, and trap that may be useful in planning further exploration. It is possible that use of advanced seismic acquisition or processing techniques applied over the complex structural terrains in high potential areas of SE Wyoming will produce new leads and, ultimately, new discoveries in addition to improved exploitation of existing oil fields. Indeed, the Play-Based CRS model we have used in this work may have relevance to re-consideration of mature regions in Wyoming or other states. In our effort, we essentially approached Southeast Wyoming the way we would approach a new area.

The second theme is to describe the occurrence in outcrop and core, of various flow units and discontinuities associated with depositional facies in the Tensleep. We continue to compile data on the abundance and arrangement of primary eolian strata and their role as key elements in reservoir heterogeneity – as well as small-scale flow units based on dune morphology and preservation - in outcrops and core in the Tensleep. This descriptive work is a necessary step in order to improve digital reservoir models run in Petrel, Eclipse, or other modeling software, or to develop new software that will improve estimates of recovery factors. The history of Wyoming includes much down-spacing of oil fields to produce bypassed reserves; and implicitly to correct original over-optimistic estimates of recovery factors that stipulated well spacing that was too great, and inappropriate EOR (usually waterflood) designs. This may be in part due to neglect of the heterogeneity produced by primary strata on oil recovery, particularly in reservoirs with low-viscosity, low-gravity oil. We have created simple models of the mechanics of the impact of eolian primary strata, mainly ripple and avalanche strata, on recovery factors in eolian reservoirs. Ultimately we plan to improve these models, and to undertake experimental work with rock samples. The plan long term is to develop engineering formulas that create more
reliable estimates of recovery factors that present methods allow. These will take into account the impact of primary strata anisotropy, cross-bed dip direction and effects of small reservoir flow units at the level of individual dunes.

Eolian petroleum reservoirs are not unique to Wyoming, although this state has an abundance of them; for example in Wyoming we have the Tensleep, Leo, Minnelusa Casper, Nugget, and Sundance Formations all of which produce oil and gas. Eolian reservoirs worldwide, such as the Rotliegend of the North Sea, commonly provide long-lived, high-volume production of both oil and gas, and importantly for Wyoming, provide new ideas from around the world that can be applied to similar reservoirs in Wyoming. As with any geologically defined unit, each oil/gas field has production characteristics peculiar to its history. However, common factors link most eolian reservoirs. Cross-stratification due to bedform migration creates preferred sweep directions and thus impacts recovery factors in fields of various maturities worldwide. Moreover, stacking of sand seas or bed forms through geological time will create distinctive flow units in subsurface petroleum reservoirs.

**Selected References**


Shell Exploration and Production, 2006, Play Based Exploration, A guide for AAPG’s Imperial Barrel Award participants, 50p.


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Abstract

The first theme of this paper is to provide an update on the stratigraphy and fluidology of the Tensleep/Casper Formation of Southeast Wyoming (parts of Northern Colorado), and oil production from these rocks. We incorporate new measured sections, stratigraphic analysis, and petrophysical work undertaken by the authors. We also discuss recent petroleum geoscience and reservoir simulation studies on the Tensleep/Casper Formations in SE Wyoming. A new outcrop site has been developed in SE Wyoming to aid in study and interpretation of outcrop as well as oilfield studies. This new outcrop has been used to create a model of the outcrop as a petroleum reservoir. Our observations on heterogeneity are helped by the fact that the lower half of the outcrop is oil saturated. Variability in oil saturation among tight and permeable/clean strata are clearly visible. Unlaminated laminites and beds tend to be oil or water whereas oil-saturated portions of the outcrop are brown beneath a thin "whitish" layer of degraded oil. Stratigraphy, secondary migration and reservoir engineering concepts are applied to explore these characteristics and their role as key elements in reservoir heterogeneity as well as at small scale. Scale units are defined by detailed petrophysical and reservoir simulation - our observations and new data obtained from the outcrop are used to develop working hypotheses that will improve estimates of recovery factors. The history of Wyoming includes much store-dumping of small-scale productive formations, and modestly to very high crude oil reserves. Estimates of recovery factors for these intervals have not been sufficiently accurate; reservoir simulation cannot be used in a meaningful way to improve these estimates. It is our contention that using the stratigraphic and petrophysical characteristics of the Tensleep reservoir will allow for greater and more accurate estimates to be made. We have identified a number of parameters that can be used to develop engineering models that can make more reliable estimates of recovery factors that present methods allow. These will then be put into the context of primary recovery and secondary recovery strategies to better develop strategies for oil recovery.

Heterogeneity reservoirs are not unique to Wyoming although this thin outcrop and these elements, for example, rock such as the Rockport Marine in the North Park area are in the same sedimentary basin. The reservoir characteristics and their potential as key elements for enhanced oil recovery are also observed in outcrops similar to the Tensleep. We have observed variations in the outcrop that can be applied to similar reservoirs in Wyoming. An example of well deposition and a few additional instances in Wyoming. Generalization of heterogeneity observations and their role as key elements in reservoir heterogeneity are here presented and applied to similar reservoirs in Wyoming. We thank the Department of Energy (DOE) for its support of the University of Wyoming research for many years. We thank Shelly for access to the Paradise Valley Oil Field. The leasehold inventory remains an important area of study in SE Wyoming and an important area of study in SE Wyoming andin the Wyoming Basin. We also thank the Wyoming Petroleum Association for its support of the University of Wyoming research for many years. Our observations on heterogeneity are helped by the fact that the lower half of the outcrop is oil saturated. Variability in oil saturation among tight and permeable/clean strata are clearly visible. Unlaminated laminites and beds tend to be oil or water whereas oil-saturated portions of the outcrop are brown beneath a thin "whitish" layer of degraded oil. Stratigraphy, secondary migration and reservoir engineering concepts are applied to explore these characteristics and their role as key elements in reservoir heterogeneity as well as at small scale. Scale units are defined by detailed petrophysical and reservoir simulation - our observations and new data obtained from the outcrop are used to develop working hypotheses that will improve estimates of recovery factors. The history of Wyoming includes much store-dumping of small-scale productive formations, and modestly to very high crude oil reserves. Estimates of recovery factors for these intervals have not been sufficiently accurate; reservoir simulation cannot be used in a meaningful way to improve these estimates. It is our contention that using the stratigraphic and petrophysical characteristics of the Tensleep reservoir will allow for greater and more accurate estimates to be made. We have identified a number of parameters that can be used to develop engineering models that can make more reliable estimates of recovery factors that present methods allow. These will then be put into the context of primary recovery and secondary recovery strategies to better develop strategies for oil recovery.

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Acknowledgements

Our work was made possible by many landlads and natural owners in the region. We were most able to Dede Bailey and the folks at Two Rivers Ranch and Joe McGuire of Medicine Bow Conservation District for access to the very important Flat Top Anticline. We also thank Dave Berberick and Brian Tisdale in the West Park Game and Fish Department for their help in accessing the data obtained from the Tensleep and Ingleside Formations on their property. Brenda and the folks at Lyons Strawberry Corporation in Lyons Colorado allowed access to definitive outcrops at their quarry. Thanks to Clinton Rock Ranch at Sand Creek for access to the lower Tensleep outcrops near the ranch and for their support of the University of Wyoming research for many years. We thank that for access to the Paradise Valley measured section in the Upper Tensleep Formations south of Laramie.

We thank Chuck M. Conley of EOR for editorial review of this paper. Thanks also to the Wyoming Geological Association for use of diagrams from various WGA publications cited in our paper (none of which go back many years). Also, many thanks to Jim Snow for use of new wapsi project on top of our new wapsi project on top of our new wapsi project. As well as local residents, particularly in the Wyoming Basin. We also thank the Wyoming Petroleum Association for its support of the University of Wyoming research for many years. Our observations on heterogeneity are helped by the fact that the lower half of the outcrop is oil saturated. Variability in oil saturation among tight and permeable/clean strata are clearly visible. Unlaminated laminites and beds tend to be oil or water whereas oil-saturated portions of the outcrop are brown beneath a thin "whitish" layer of degraded oil. Stratigraphy, secondary migration and reservoir engineering concepts are applied to explore these characteristics and their role as key elements in reservoir heterogeneity as well as at small scale. Scale units are defined by detailed petrophysical and reservoir simulation - our observations and new data obtained from the outcrop are used to develop working hypotheses that will improve estimates of recovery factors. The history of Wyoming includes much store-dumping of small-scale productive formations, and modestly to very high crude oil reserves. Estimates of recovery factors for these intervals have not been sufficiently accurate; reservoir simulation cannot be used in a meaningful way to improve these estimates. It is our contention that using the stratigraphic and petrophysical characteristics of the Tensleep reservoir will allow for greater and more accurate estimates to be made. We have identified a number of parameters that can be used to develop engineering models that can make more reliable estimates of recovery factors that present methods allow. These will then be put into the context of primary recovery and secondary recovery strategies to better develop strategies for oil recovery.

The Ingleside Formation (Casper-Tensleep correlatives) at Owl Canyon, Colorado. We measured two sections in this area for comparison with nearby outcrops. View to the northeast.

The Upper Tensleep Formation at Flat Top Anticline near Medicine Bow, Wyoming. Several measured sections here have been used to create a model of the outcrop as a petroleum reservoir. Our observations on heterogeneity are helped by the fact that the lower half of the outcrop is oil saturated. Variability in oil saturation among tight and permeable/clean strata are clearly visible. Unlaminated laminites and beds tend to be oil or water whereas oil-saturated portions of the outcrop are brown beneath a thin "whitish" layer of degraded oil. Stratigraphy, secondary migration and reservoir engineering concepts are applied to explore these characteristics and their role as key elements in reservoir heterogeneity as well as at small scale. Scale units are defined by detailed petrophysical and reservoir simulation - our observations and new data obtained from the outcrop are used to develop working hypotheses that will improve estimates of recovery factors. The history of Wyoming includes much store-dumping of small-scale productive formations, and modestly to very high crude oil reserves. Estimates of recovery factors for these intervals have not been sufficiently accurate; reservoir simulation cannot be used in a meaningful way to improve these estimates. It is our contention that using the stratigraphic and petrophysical characteristics of the Tensleep reservoir will allow for greater and more accurate estimates to be made. We have identified a number of parameters that can be used to develop engineering models that can make more reliable estimates of recovery factors that present methods allow. These will then be put into the context of primary recovery and secondary recovery strategies to better develop strategies for oil recovery.

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Cross section

Index map of Wyoming and counties, showing State database of Tensleep Penetrations (Tensleep, Casper, Minnelusa). Our study area is shown by red box with Upper Tensleep Thickness posted. Not every Tensleep penetration was used in our regional study. Older wells with poor logs or little data were omitted, as well as those grids of intra-field wells such as those at Wertz and Lost Soldier.

Regional Tensleep Stratigraphic cross section

Exhibit map of Wyoming and counties, showing State database of Tensleep Penetrations (Tensleep, Casper, Minnelusa). Our study area is shown by red box with Upper Tensleep Thickness posted. Not every Tensleep penetration was used in our regional study. Older wells with poor logs or little data were omitted, as well as those grids of intra-field wells such as those at Wertz and Lost Soldier.

Memorial Operating
102 ABC Unit 103 (Wertz)
JWHE sec 7 T28N R79W
API 49-007-21004

Wolf Energy Company
Kerfoot Creek Unit 1
SWSE sec 15 T29N R79W
API 49-007-06982

Wolf Energy Company
Black B Unit 1
NWSE sec 18 T25N R76W
API 49-001-05393

Union Oil of California
UPRR 44G 21 1
SESE sec 1 T22N R75W
API 49-007-21003

Gibson JW
Champlin 1-19
NWSW sec 19 T24N R75W
API 49-001-20003

100 feet

Goose Egg

Freezout

Ervay

Difficulty

Forelle

Minnekahta

Opechee

Sybille

Upper Tensleep

Lower Tensleep

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Upper Tensleep

Lower Tensleep

Lower Permian (Wolfcampian) isopachs In Eastern Wyoming

Black Hills

Upper Permian (Casperian) isopachs In Eastern Wyoming

Amsden

Madison

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

Distribution and thickness of interval A of Paleotectonic maps

Interval A of Paleotectonic maps

Lower Permian (Wolfcampian) isopachs In Eastern Wyoming

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Interval A of Paleotectonic maps
The Sand Creek measured section was chosen at a locality that shows the transition upward from the red siltstones and arkosic fluvial sands of the Fountain Formation to the eolian dunes of the Casper Formation. The section is relatively complete, lacking only the upper 30 ft or so of Casper below the Stanka red siltstones. There is a major change in wind direction from northward-directed to southward-directed at unit 18. The section as a whole is a classic “cleaning upward” type, reflecting both the sorting of older fluvial sediments from the Fountain, and in the end, the arrival of sand transported long-distances from the Pennsylvanian sand seas to the north. At a nearby well north of the outcrop (Champlin 1-19), the Fountain formation has thinned and disappeared. This is typical of the Fountain in the Laramie basin. It seldom extends very far northward or westward of the old Pennsylvanian age uplifts.

### Sand Creek, Wyoming Measured Section

**Fluvial and pond sediments**

A carbonate pond deposit with very, irregular bedding. This represents a sealed pond within and basinal dolomite (white) table is close to the surface. The unit is bioturbated; there is no direct evidence of eolianites. This unit was encountered about the level of sample 56 in the measured section.

A fluvial channel filled with coarse red mud, cut into fluvial sandstones, near base of the Tensleep (Casper) Formation, shows an interfingering carbonate/ eolian facies that is marked by white arkose. The rest of the deposit is typical of the lower Tensleep (Casper) Formation, showing up to 10 ft of strata that comprises a channel that has been cut into the Tensleep sand and carbonate section. In the short distance northward to this well, most of the fluvial recycling of Front Range granite sandstones, and Fountain Formation has vanished. Thus, the Sand Canyon area provides a glimpse into how the Tensleep sand and carbonate section were formed by recycling older Pennsylvanian Fountain Formation.

**Eolian sediments**

A soil horizon in flat bedded (fluvial?) sands; with immediately below the sabkha shown on the cross section. Such deposits form from the interaction of eolian and fluvial sediments. This is typical of the Fountain in the Laramie basin. It seldom extends very far northward or westward of the old Pennsylvanian age uplifts.

Eolian sabkha deposits of Upper Tensleep (Casper) Formation on sand creek. The channel shows a carbonate bed with poorly sorted sabkha mud. The sabkha above (flat laminations and inverse grading lower left) is overlain by eolian dunes. Above the sabkha, interbedded sandstone, near the base of the rock-bottom, was used in the measured section, showing mostly eolian sand dunes, very porous and permeable comprises the Upper Tensleep above the Lower Tensleep sand and carbonate section. The major change in wind direction from northward-directed to southward-directed at unit 18 well north of the outcrop (Champlin 1-19), the Fountain formation has thinned and disappeared. This is typical of the Fountain in the Laramie basin. It seldom extends very far northward or westward of the old Pennsylvanian age uplifts.

Matt Johnson pauses for scale in this image of the upper part of the Sand Creek measured section, behind him the eolian cross beds from which sample SC 080/09 was taken. The uppermost part of the Sand Creek measured section is a thick section, biostratigraphic stratigraphy is typical of the lower Tensleep (Casper) Formation, showing mostly eolian sand dunes, very porous and permeable comprises the Upper Tensleep above the Lower Tensleep sand and carbonate section. In the short distance northward to this well, most of the fluvial recycling of Front Range granite sandstones, and Fountain Formation has vanished. Thus, the Sand Canyon area provides a glimpse into how the Tensleep sand and carbonate section were formed by recycling older Pennsylvanian Fountain Formation.
Tensleep Sandstone at Flat Top Anticline
Carbon County, Wyoming (ft.)

Extended bounding surfaces outlining possible reservoir flow units (red lines)

Sabkha perm barriers
Interbed perm barriers
Primary strata perm barriers

Sabkha perm barriers

East Allen Lake Oil field structure

After Kelly, 1984 Primary strata perm barriers

Density-Grp log of the Federal 1 Allen Lake East well that juxtapose 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 (shown).
White Rock Canyon Upper Tensleep

The Upper Tensleep Sandstone at White Rock Canyon, east side of the outcrop. Out 226 feet (partial) measured section begins in the Upper Tensleep, which in this area is roughly 400 feet thick, based on local well control. It was measured on the opposite (west) side of this cliff where access was easier. The Upper Tensleep Sandstone at White Rock Canyon, east side of the outcrop

The variety of genetic units 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 in perforation, lithology etc. Thrust fault zone of deformation shown by red lines.

Upper part of the measured section covering mainly of eolian dunes with unusual sand and small outliers of reddish yellow sandstone.

View of the outcrop from the east side reveals complexity of individual genetic units with some of them possibly as fans formed at submarine structures. Red/Gray sandstone indicated by arrow.

A small fluvial channel with cross-bedded sand and tephrugous bedding. Tephrugous bedding (bottom dashed line) is enclosed by flume sands above and below. Unit 18 shown above, pink-gray of section units 19-21.

The Upper Tensleep Sandstone measured section in terms of thickness, shape and crossbedding. This suggests primary strata types: ripple, bedform, gray

90% of this outcrop is ripple strata, despite the presence of stratification shown by red lines.

A small fluvial channel with cross-bedded sand and tephrugous bedding. Tephrugous bedding (bottom dashed line) is enclosed by flume sands above and below. Unit 18 shown above, pink-gray of section units 19-21.

The Upper Tensleep Sandstone at White Rock Canyon, east side of the outcrop

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Paradise Valley Measured Section

Close up view of a set of avalanche strata on a dune slipface at the base of the measured section. This is Unit 1 of the measured section. Crossbedded unit above the erosional bounding surface consists of stacked sets of strata of Unit 2, which overall has higher proportion of ripple primary strata to avalanche strata, perhaps because the preserved bedforms are smaller.

Lower part of the Paradise Valley measured section with dune bedforms, whose cliffs are scored taking notes. Generally, bedforms become smaller up section. This sequence was measured section is made up of a complex paraboles intermixed with numerous distinctive flow units. The first few units are probably the dunes themselves at the base of the cliff before the dashed line, due to a predominance of permeable avalanche strata.

Small scale eolian sedimentary structures at Paradise Valley measured section. The diagram shows 375 dip and strike directions to SE. The main structures are typical of eolian ripple strata. The dip and strike of the cross bed laminae are highly variable.

A close-up view of a set of avalanche strata on a dune slipface at the base of the measured section. This is Unit 1 of the measured section. Crossbedded unit above the erosional bounding surface consists of stacked sets of strata of Unit 2, which overall has higher proportion of ripple primary strata to avalanche strata, perhaps because the preserved bedforms are smaller.

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Upper Fountain-Ingleside Fm Lien Quarry and Owl Canyon Northern Colorado

Below: Fountain-Ingleside outcrop: locality of our measured section along U.S. Highway 287

Our section (shown to the right on this page) begins in the Upper Fountain Formation. The transition to Ingleside is in the upper right (pink). To our surprise, we found considerable eolian sand and sand sheet tops within the dominantly fluvial Fountain. These commonly had a pink color. One of these units is marked by the arrow on the left.

Upper part of the measured section (mainly Permo-Triassic) is covered by a thin limestone which was removed by erosion. Eolian sandstone and interbedded sandstones and mudstones are present. These are typical facies in the upper part of the upper Tensleep Ss, purple, massive, burrowed horizons (soil?).

Sequence may be derived from previous unit (unit 5) which consists of massive brown arkosic sandstones. It continues into mixed eolian, fluvial and marine sediments of the upper Tensleep.

The clasts shown here are all the remnants of a thin fluvial sheet that was transported and deposited elsewhere (and then reworked into fluvial). The top of Unit 6 consists of a thin eolian sand sheet (unit 7) only a few inches thick (gray) which records the reworking of the dune sands.

Below right: The clasts shown here are all the remnants of a thin fluvial sheet that was transported and deposited elsewhere (and then reworked into fluvial). The top of Unit 6 consists of a thin eolian sand sheet (unit 7) only a few inches thick (gray) which records the reworking of the dune sands.
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**Tensleep stratigraphy**

**Upper Tensleep thickness**

Upper 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 follows the Cheyenne Belt of deformation.

**Upper Tensleep Hydrocarbon shows and Structure**

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 limited core and sample data. This map also shows major faults in red from the state geological map, and structure contours are 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.

**Total Tensleep thickness**

The thickness of the Upper and Lower Tensleep combined follows the pattern of the Upper Tensleep. It is clear that major Laramide uplifts of the Medicine Bow and Sierra Madre Mountains have stripped off the Tensleep. There are also more subtle trends related to local faulting.

**Satanka Shale thickness**

Satanka Shale thickness map (overlies Tensleep regionally, thus this is basically a top seal map where the Satanka is not zero thickness). Areas with Satanka eroded are colored purple. Orange shading shows thick Satanka (greater than 100 feet) in southern Laramie Basin.

**Satanka Shale thickness**

Satanka Shale-thickness map (overlies Tensleep regionally, thus this is basically a top seal map where the Satanka is not zero thickness). Areas with Satanka eroded are colored purple. Orange shading shows thick Satanka (greater than 100 feet) in southern Laramie Basin.

**Sybille carbonate-evaporite thickness**

Sybille carbonate-evaporite sequence of the Goose Egg Formation immediately overlies the Satanka Shale. The thickness is a good indication of post-Tensleep tectonics. Thick Sybille is present in the Lost Soldier-Wertz area, Hanna Basin and a NE-SW trending area defined by faults in the Laramie Basin that may indicate early fault movement. On this map, thicks are indicated by purple shading, thins by orange.
Play Based exploration (PBE) and Common Risk Segment (CRS) evaluation

Play Based exploration is a method used to build-up, then leverage regional understanding of basins and petroleum systems, in both mature and immature basins, to the specific geological plays they contain. The benefits lie in providing an early focus to a range of exploration or production activities.

The multi-scale approach (from basin to prospect scale within a petroleum system) provides greater technical rigor, and hence quicker, more confident E and P decisions, even with partial or incomplete data. New play growth, or rejuvenation of older plays is enabled by the creativity and innovation that can be unleashed most effectively at the level of basin or petroleum system understanding.

The PBE methodology is encapsulated in the “Exploration Pyramid” (see cartoon on right), where the initial focus is on the basics - the determination and description of the regional context and the basin framework leading to an understanding of the working petroleum system(s).

Petroleum system understanding forms the basis for the subsequent play focus - quantifying the various aspects of the system within each play, and using tools such as common risk segment mapping to highlight sweet spots within each play. The focus of the EORI CRS mapping within PBE method is shown by the red dots and arrows on the figures on this page. CRS mapping can involve quantitative Possibility of Success estimates (POS) or reflect “low risk” versus “high risk” determinations made using the regional geological overview. These estimates are stacked in a program such as ArcGIS (see diagrams at bottom of page). Areas in which reservoir, charge and trap are best, and overlap geographically, will focus both exploration and production opportunities. EORI currently works at the CRS play segment level; we do not target prospects per se, although some attractive ideas occasionally emerge from our databases.

When the CRS “low risk” areas have been mapped by EORI and where possible, quantified, the focus shifts to operators who may choose to create more detailed geological and geophysical analysis to define prospects within each play, and build a portfolio, including making estimates of volumes, risk and uncertainty. It is at this stage the seismic data and consideration of field level petrophysics come under consideration, especially in the evaluation of field acquisition or development choices.

Play based exploration (PBE), admittedly, requires up-front investment of time if the regional play framework has not already been defined. However, that investment will be repaid by swifter and simpler assessment of individual prospects, and in the quality of subsequent decisions by industry.

This page was greatly benefited by the Shell Exploration and Production Play Based Exploration guide. We express our thanks.

The working definitions shown above are used in PBE analysis of this poster. Our work focuses on CRS mapping of the Upper Tensleep in Southeast Wyoming, at the play segment level. We also use and constructive elements building from the bottom of the list including the petroleum system and play to weigh evaluation of individual play segments.

The logic of sweet spot identification involves the stacking of positive geological indicators that collectively fulfill the requirements for the existence of an oil field or a very productive region of a basin. The common overlap area in which all factors are positive, or “low risk” in terms of presence is a natural sweet spot. This approach is usable at basin, CRS play segment and prospect scale.
Stratigraphy, Exploration and EOR potential of the Tensleep/Casper Formations, SE Wyoming
Steven G. Fryberger, Nick Jones, Matthew Johnson and Curtis Chopping
Enhanced Oil Recovery Institute, University of Wyoming 2016

**Tensleep CRS Overview**

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 assessment of CRS segments is commonly a matter of judgment by an experienced geologist about relative risk in terms such as “low risk of no charge” versus “high risk of no charge” for example. These understandings can also be attested as possibilities for success (P50) as percentages from zero to 100, or statistical categories such as P5-P95-P99 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), but our values are relative, that is, expressed as “high-risk-low risk” etc. and not quantified further.

The maps on this page illustrate elements used in construction of a basic “common risk segment” map of the Tensleep Formation in Southeast Wyoming. The combined CRS map is displayed immediately to the right of this text. Not surprisingly, the composite CRS map for “low risk” that exists Tensleep production (red areas on map are oil fields). However, study of the maps depicting reservoir quality, structure and charge (shown) reveal why the fields are where they are, and highlights trends that would not be obvious without this technique. This may perhaps encourage further work in these regions, and this may lead to further discoveries even in this mature petroleum province.

**Tensleep Formation Common Risk Segment Maps**

**Upper Tensleep Combined CRS map**

Combined Upper Tensleep Common Risk Segment (CRS) map. Green areas show regions with the best chance to find new production (highest risk). Blue areas show moderate risk. Red hachured areas show high risk areas, mainly regions such as the Hanna Basin with deep basinized, tight Tensleep, or areas with insufficient evidence for robust structural traps, State of Wyoming basement map as background.

**Tensleep Trap Risk**

Tensleep trap (structures) common risk segment (CRS) map. Contours shown show the subsea top Tensleep from correlative data records. Green shading is low risk of not finding a commercial structure. Blue shading in moderate risk. Purple shading is high risk. Major regional faults are shown by red lines, background is the Wyoming Basemap map. This map is based on the distribution of known producing structures in Tensleep, level, and structural setting. In Southeast Wyoming, there do not appear to be stratigraphic traps above intraformational (reservoir heterogeneity) level. High-risk area near Boislands is related to very shallow depth of Tensleep, with exposure of the formation in places along the ridge that runs from Sinclair north towards Maloney Dome.

**Upper Tensleep Trap Risk**

**Upper Tensleep Reservoir risk (quality)**

Tensleep reservoir common risk segment (CRS) map (quality) based on porosity and permeability of Upper Tensleep sandstones. Contours show cutoffs in Upper Tensleep, with red cutoff at 65 mD (100% porosity), thus this is a conservative map. The map does not consider fracture-dependent production/exploration opportunities. Green, low risk; Blue moderate risk; purple; high risk. Regional faults shown as red lines, State of Wyoming basement map as background.

**Southeast Wyoming seismic trade data**

Availability of trade seismic data in southeast Wyoming (sample). 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 is background of the Wyoming Basemap map. Seismic data is courtesy of SI Seismic Exchange data brokers in Houston and Denver. Other trade data is available.
The Quealy Dome low risk CRS play segment is characterized by numerous oil shows on drill stem tests and Tensleep production at Quealy, Herrick, and Little Laramie oil fields. The structure - as visible on the Wyoming Geological Survey basement map, and on subsurface contours (based on wells) - is complex. Unfavourable area local closures, outcrops and fault traps may remain. This complexity noted by Stone (1995) is consistent, and any wonder of older 2D seismic data has been processed in ways that image this complexity properly. The source rock may or may not be the Phosphoria Formation in this region.

The Lost Soldier-Wertz low risk CRS area is notable for those two very large Tensleep fields, as well as a few smaller ones such as Mahoney Dome. 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 geologically, awaits the "new idea in an old area" concept if it is to contribute more reserves. It might be worth a review of older seismic to make sure that processing and acquisition parameters are up to date, and that no prospective thrust faults have been overlooked, or structural closures incorrectly mapped due to time-depth calculation errors in original processing.

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Tensleep oil fields in SE Wyoming are mainly structural traps. However, it is likely that recovery factors from these fields are heavily influenced by oilfield reservoir heterogeneity at multiple scales that we observed repeatedly in core and outcrop. Similar to oilfield reservoirs worldwide (Fryberger and Hess, 2014). Evidence for some of this heterogeneity is presented on this slide from primary strata to larger-scale- sized genetic units that are obviously flow units due to manifest poroperm differences observed in core.

**Field Map and Data after Potter, 1984.**

**Permeability variations from Page Sandstone outcrop in Northern Arizona.** There is about one order of magnitude difference in permeability between “sandstone” and “grain flow (avalanche)” deposits. Albert, Chatterji, et al. 1986.

**Pressure-psi and thickness of lower Tensleep at Wertz Oil Field.**

**Wertz 46.**

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

**2012-2016. Legacy Reserves Operating LP (Corinthian Energy) April 2015 Tonsley Primary vs. Upper Tensleep.**

**Initial Production**

**Pressure-psi**

**Water Flow Directions created by microscopic permeability at small (millimeter) scale in unaided and rippled strata.** These are predicted using data from interporosity measurements in the Middle Jurassic Page Sandstone (shown in image below). Rock arrows are proportional in length to directional permeability along primary strata. These data points do not show the injection of sweep efficiency and recovery factors due to intra-wells for oil created by primary strata. After Chatterji, et al. 1986.